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Volume I

Executive Summary

February 1975

Tug Fleet and Ground Operations Schedules and Controls

MARTIN MARIETTA

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TUG FLEET AND GROUND OPERATIONS SCHEDULES AND CONTROLS

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FOREWORD

This final report, submitted in accordance with Data Procurement Document number 480 dated June 1974, contract NAS8-31011, is published in three volumes:

Volume I - Executive Summary (DRL MA-04)

Volume II - Part I Final Report (DRL MA-03)

Part II Addenda (DRL MA-03)

Part III Appendixes (DRL MA-03)

Volume III - Program Study Cost Estimates (DRL MF003M)

The content of each volume is shown in the diagram on the following page.

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TUG FLEET AND GROUND OPERATIONS SCHEDULES AND CONTROLS, FINAL REPORT (NAS8-31011)

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ABSTRACT

This study presents Tug Fleet and Ground Operations Schedules and Controls plan. This plan was developed and optimized out of a combination of individual Tug program phased subplans, special emphasis studies, contingency analyses and sensitivity analyses. The subplans cover the Tug program phases: Tug operational, Interim Upper Stage (IUS)/Tug fleet utilization, IUS/Tug payload integration, Tug site activation, IUS/Tug transition, Tug acquisition. Resource requirements (facility, GSE, TSE, software, manpower, logistics) are provided in each subplan, as are appropriate Tug processing flows, active and total IUS and Tug fleet requirements, fleet management and Tug payload integration concepts, facility selection recommendations, site activation and IUS to Tug transition requirements. The impact of operational concepts on Tug acquisition is assessed and the impact of operating Tugs out of KSC and WTR is analyzed and presented showing WTR as a delta. Finally, cost estimates for fleet management and ground operations of the DDT&E and operational phases of the Tug program are given.

GLOSSARY

A&E	Architectural and Engineering
APS	Auxiliary Propulsion System
C&W	Caution and Warning
CCB	Configuration Control Board
CCMS	Command Control Monitoring System
CDS	Central Data System
CKAFS	Cape Kennedy Air Force Station
COR	Contracting Office Representative
CST	Combined Systems Test
CTMCF	Common Tug Maintenance and Checkout Facility
DA	Double Amplitude
DOD	Department of Defense
EMC/EMI	Electromagnetic Compatibility/Interference
ETR	Eastern Test Range
F/C	Fuel Cell
FCR	Facilities Change Request
FECP	Facilities Engineering Change Proposal
FIT	Functional Interface Test
FMEA	Failure Modes and Effect Analysis
FWG	Facility Working Group
GSE	Ground Support Equipment
HIM	Hardware Interface Module
H.P.	High Pressure
I/F	Interface

I/O	Input/Output
IOC	Initial Operational Capability
IUS	Interim Upper Stage
JSC	Johnson Space Center
KPF	Kick Stage Processing Facility
KSC	Kennedy Space Center
LCC	Launch Control Center
L.P.	Low Pressure
LPS	Launch Processing System
LRU	Line Replaceable Unit
MDF	Mate-Demate Fixture
MIC	Management Information Center
MPS	Main Propulsion System
MSFC	Marshall Space Flight Center
MSI	Maintainability Significant Item
MSS/PSS	Mission Specialist Station/Payload Specialist Station
MTBF	Mean Time between Failure
MTBR	Mean Time between Repair
NASA	National Aeronautics Space Administration
NN/D	Non-NASA/DOD
O&M	Operation and Maintenance
OFI	Operational Flight Instrumentation
OIS	Operational Intercommunication System
OLF	Orbiter Landing Field
OMD	Operations Maintenance Documentation

OMI	Operational Maintenance Instruction
OPF	Orbiter Processing Facility
PCR	Payload Changeout Room
P/L	Payload
PMF	Payload Mate Facility
PPR	Payload Processing Room
RFP	Request for Proposal
RMS	Remote Manipulator System
RTG	Radioisotopic Thermal Generator
S&E	Science and Engineering
SAWG	Site Activation Working Group
S/C	Spacecraft
SCF	Satellite (Spacecraft) Control Facility
SGLS	Space Ground Link System
SHE	System Health Evaluation
SPF	Spacecraft Processing Facility
SSPD	Space Shuttle Payload Description
SRT	Supporting Research and Technology
STDN	Space Tracking and Data Network
STS	Space Transportation System
TBD	To be determined
TPF	Tug Processing Facility
TSE	Transportation Support Equipment
VAB	Vertical Assembly Building
VSWR	Voltage Standing Wave Ratio
WBS	Work Breakdown Structure

I Introduction

I. INTRODUCTION

The Space Shuttle is being designed to provide economical transportation to and from low earth orbit. The mission model, however, also identifies missions to higher energy orbits and/or to the planets. In order to accomplish these high energy missions, additional propulsive stages are required.

The propulsive stages for performance of the high energy missions fall into three categories: the Interim-Upper-Stage (IUS), the Tug, and their associated kick stages. The IUS will be developed first, by DOD, with an operational date compatible with the operational date of Space Shuttle. The Tug will be developed by NASA for use during the 1983 to 1991 time frame. A transition period of at least one year is anticipated whereby both IUS and Tug will be used for accomplishment of high energy missions.

Previous Tug system studies basically provided ground operations requirements and concepts with limited information for the planning and fleet operations phases. No attempt had been made to analyze the interrelationships of these phases for optimizing overall program benefits or analyzing Tug fleet operational risk factors by studying the planning and operational phases as a "system." The preplanning and integration of the Tug with other elements of the STS and the Tug fleet operations phase had not been analyzed in sufficient detail for supporting midrange to long range program planning. An overall plan addressing both ground operational data and technical requirements that span the IUS/Tug planning and operations phases while narrowing options with emphasis on more significant trade studies,was required.

The Tug Fleet and Ground Operations Schedules and Controls Study addresses both ground operational data and technical requirements that span the Tug planning and operations phases. A companion study performed under another NASA contract and covering mission operations provides complimentary flight operations details. The two studies together provide operational planning data requirements, resource allocation, and control milestones for supporting the STS program.

In many previous aerospace programs, the operations phase requirements have been considered too late to affect design and development or the acquisition phase. This has not always resulted in the most efficient operation, nor has it been cost effective, but rather one that was forced to accommodate fixed designs and hardware configurations.

NASA recognized this problem early in the Space Tug program. Consequently, two of the objectives of this study were to provide early operations phase inputs into hardware designs and interfaces. Operations phase considerations such as access for maintenance, checkout, and servicing and postmission safing considerations were analyzed and inputs were provided to support the Shuttle PDR and influence early Space Tug design and development concepts.

A third objective was to develop and optimize ground operations planning for Tug baseline definition. This planning data supported the concurrent series of contractor studies.

The final objective of this study was to develop preliminary planning for management methods, such as fleet utilization scheduling techniques, and performance measurement systems that would support and implement the ground operations planning.

The study was based on the Tug defined by *Baseline Space Tug Configuration Definition*, MSFC 68M00039-2, as shown on Figure I-1. It is a cryogenic vehicle 30 ft (9.14 m) long and 176 in. (4.47 m) in diameter, made up of an LH_2 tank, LO_2 tank, an RL-10 derivative IIB main engine with an extendable nozzle and a body shell consisting of a forward skirt, main skirt, and aft adapter. It has a hydraulic system for main engine actuator control, and an active and passive thermal control system to regulate heating loads. A helium pressurant system is included for purging, valve control, and tank pressurization. The auxiliary propulsion system consisting of four thruster pods is provided for vehicle control and maneuvering. The Tug has a navigational guidance and control system, a data management system, a rendezvous and docking system, a measuring system, and an electrical power and distribution system.

The IUS used for this study is that stage defined by NASA letter PF02-74-156 dated August 19, 1974 and McDonnell Douglas Astronautics Company *Reference Information on Interim Upper Stage (IUS)/Satellite Interfaces for Use in IUS/Tug Payload Requirement Study*, July 1974. The kick stages are those defined by the same NASA letter and McDonnell Douglas Astronautics Company *Definition of Kick Stages to be Used in OOS/Tug Payload Requirement Compatibility Study*, 15 August 1974.

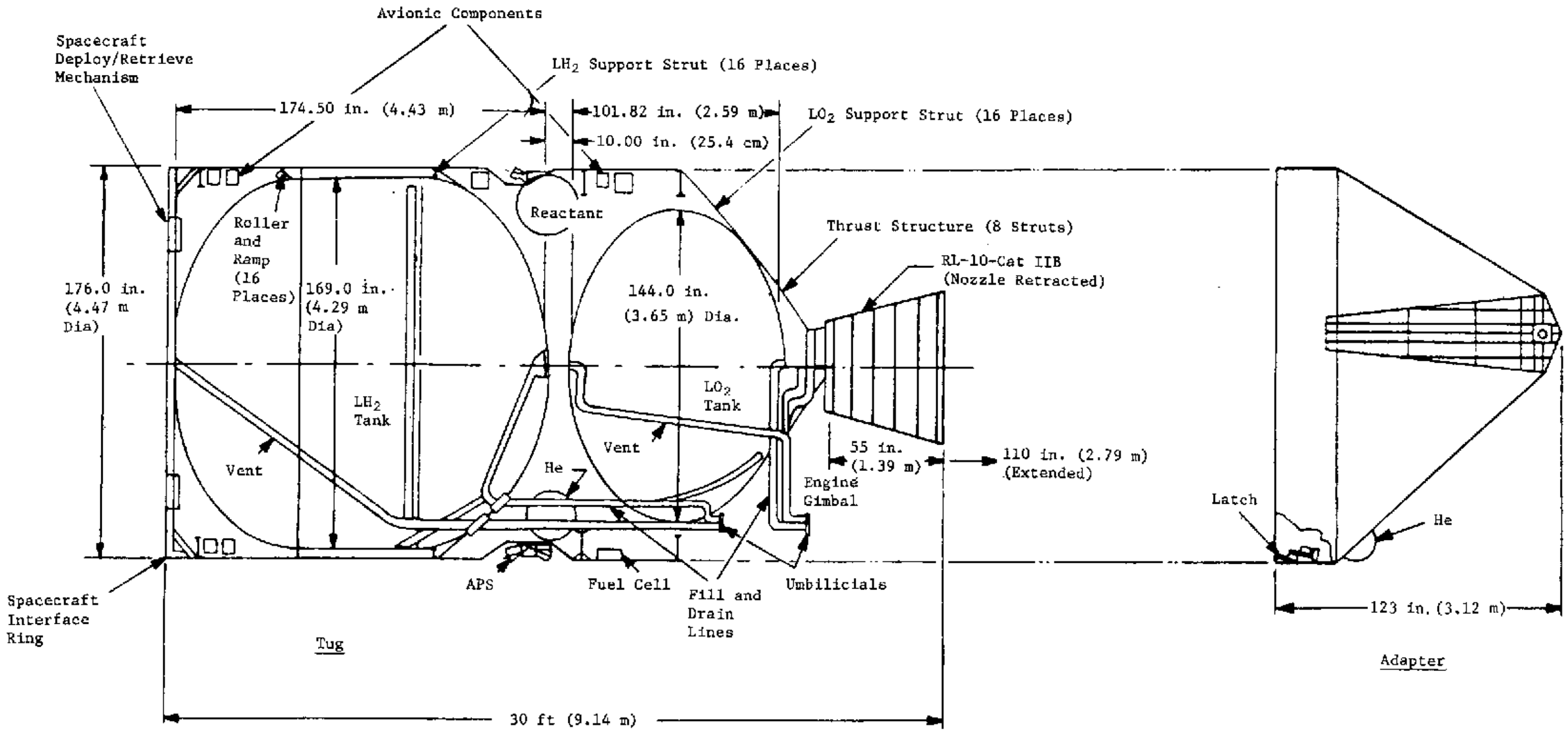


Figure I-1 Baseline Space Tug General Arrangement and Size

II Method of Approach

II. METHOD OF APPROACH

The essence of the study approach is shown in Figure II-1. The study tasks spanned three distinct phases. In phase 1, "strawman" processing flows, timelines, and resource requirements were developed. In phases 1 and 2, numerous trades were performed to optimize the "strawman" processing flows. Where additional depth of analysis was required, special emphasis assessments were performed under task 2.0 to compliment and expand the "greenlight" single-cycle processing flows.

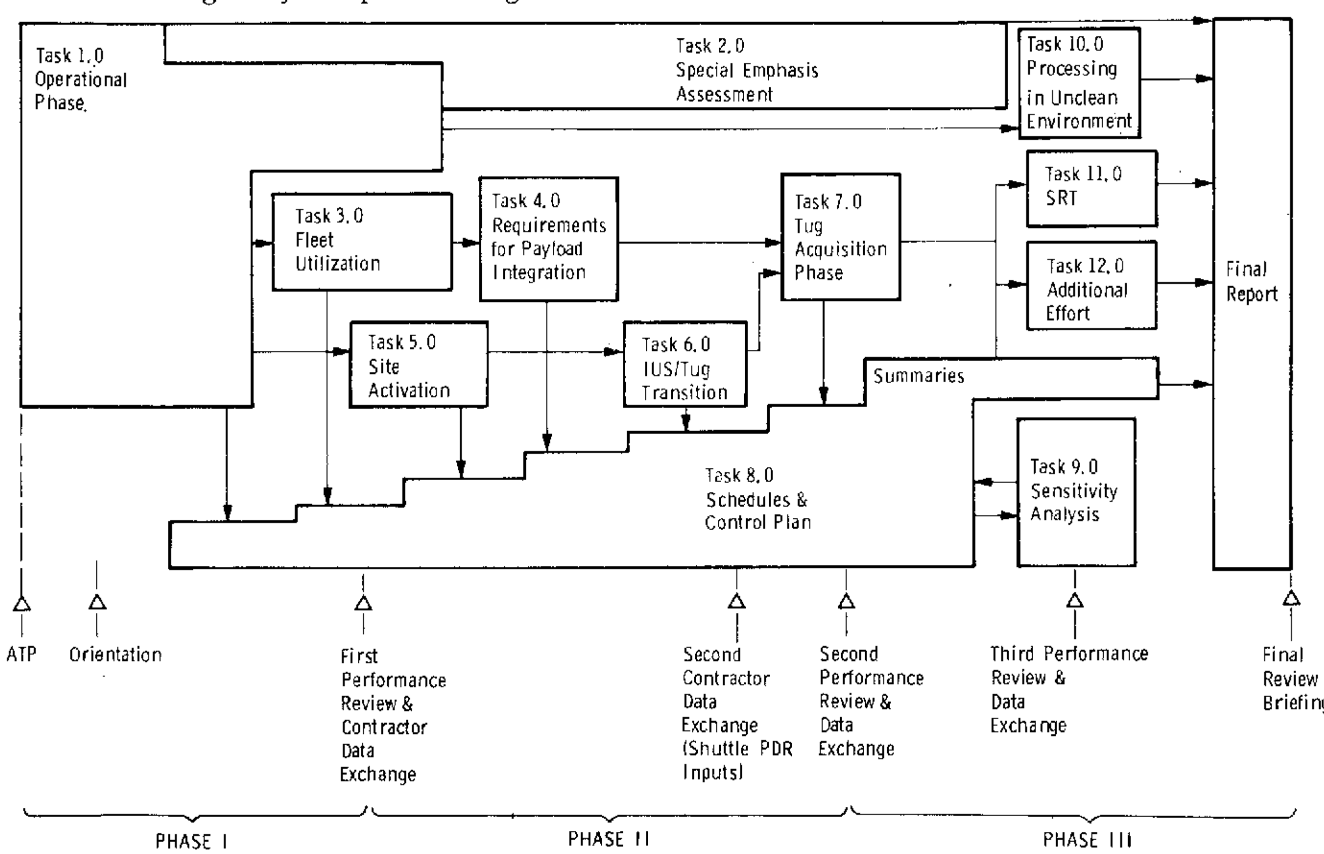


Figure II-1 Study Flow Summary

Subsequently, the study operated on these optimized flows to develop requirements for other program phases. In task 3.0, the traffic impact was considered to establish the Tug fleet size. Contingency analysis was employed to realistically size the fleet under other than nominal conditions. Fleet management techniques were developed. In task 5.0, the site activation requirements for the Tug were defined, based on the operational data developed earlier. The transition from IUS to Tug was analyzed in task 6.0, giving special consideration to the period of time when concurrent IUS and Tug operations may be required. Task 4.0 determined the requirements for Tug to spacecraft integration in the mission planning era addressing such issues as Level I integration concepts and multiple spacecraft integration.

Finally, in phase 3, the results of tasks 1.0 through 6.0 were analyzed to determine the impact on Tug design and development (acquisition phase, Task 7.0). Task 10.0 assessed an alternative concept for processing the Tug in an as-received condition in a factory clean environment. Each task resulted in a subplan that was integrated in task 8.0 into an overall plan. The subplan elements were then subjected to a sensitivity analysis in task 9.0 before finalization. Task 11.0 defined Supporting Research and Technology. Recommended Additional Effort was defined in task 12.0.

Figure II-2 summarizes some of the more important ground processing concepts that were developed in the study. For nominal Tug processing, factory clean environment in the VAB low bay is recommended. Two processing cells are required with an LPS terminal. Level I off-line integration is performed in the TPF cell using selected Orbiter simulation. Multiple spacecraft buildup is performed off-Tug to reduce the turnaround times.

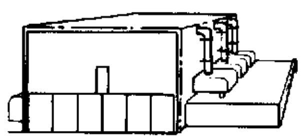
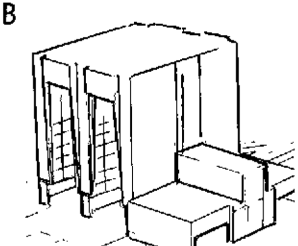
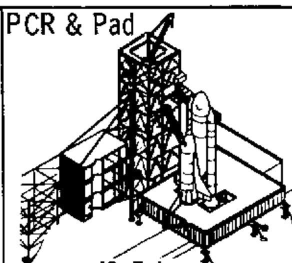
	OPF  ← 19.5 hrs →	VAB  ← 97 hrs →	PCR & Pad  ← 43.5 hrs →
Facility	Tug Safing Provisions Tug/SC Separation Area	2 Vertical Cells Factory Clean Environment LPS Terminal Orbiter Simulation	Pad Changeout Room Loading Provisions
Activities	Safing Removal Of Payload Separation	Final Safing Refurbish & C/O Clean To Visibly Clean S/C Mate Off-Tug Multiple S/C Integ. P/L To Orbiter I/F Verif. APS Load Partial Pressurant WTR Tug Processing Kick Stage Mate	Payload Installation Final Pressurant Fuel Cell Reactants MPS Load MLI Purge Countdown/Launch
Options/ Contingency	Payload Inst'l (Horizontal)	IUS Processing & Checkout	SC Mate & Integration Payload Changeout

Figure II-2 Space Tug Processing Requirement Summary

For contingency situations, the capability to perform spacecraft/Tug mate and integration at the PCR should be provided. Payload changeout provisions at the pad provide very valuable flexibility and that capability should be retained. Similarly, although vertical installation at the pad is recommended, horizontal installation at the OPF should remain open as an option.

The study results indicate that the most cost effective approach to WTR launches is to perform all maintenance and checkout at ETR. Tugs would then be ferried to WTR where spacecraft integration would occur in the PPR.

Table II-1 provides a summary of the programmatic recommendations of this study. Each of these recommendations will be discussed in the appropriate section of this report.

Table II-1 Programmatics Recommendations Summary

Payload Integration	
Tug Project Performs Analytical and Physical Integration	
Tug User Guide Developed Early	
Software Integration in Simulation Lab	
Activation	
Engineering Model Required (Pathfinder)	
Recognize Impact on Launch Pad/Orbiter	
Fleet Utilization	
Mechanized Utilization Planning	
Contingency Provisions in System	
747 Canister Transportation (Piggyback)	
Spares PRocurement Deferred	
Tug Block Build/Delivery Considerations	
Fleet Sizing	
13 to 16 Total	
Optimize Expendable Utilization	
Backup Tug and Kick Stage in Active Fleet	
WTR Delta	
Provide Minimum Launch Capability	
Process and Refurbish Tugs at ETR	
Average Tug Cost per Flight for Ground Processing	$679.11K

The Tug Fleet and Ground Operations Schedules and Control study has made significant contributions to the Space Tug operational planning. Most importantly, it has served as a sounding board by which various operational concepts could be evaluated for Tug system applicability. This document describes the derivation of these recommended concepts and demonstrates that one vital element of Space Tug ground operations costs is operational flexibility.

III Basic Data and Significant Results

III. BASIC DATA AND SIGNIFICANT RESULTS

A. PROCESSING REQUIREMENTS (TASK 1.0)

The processing flows, activities, and timelines provide a vehicle for defining resources and servicing requirements for the Space Tug at the operational site. The fact that the flow developed five years in advance of detailed design is a "strawman" and not the actual flow of the flight Tug, is of small consequence to this study. The important thing is that it represents the type of flow and maintenance/checkout activities that will be required eventually. These requirements then form the basis for assessing the effect of the operational requirements on other phases of the program. In this respect, development of realistic processing requirements was critical to the validity of the study results.

Processing requirements were developed using the approach shown in Figure III-1.

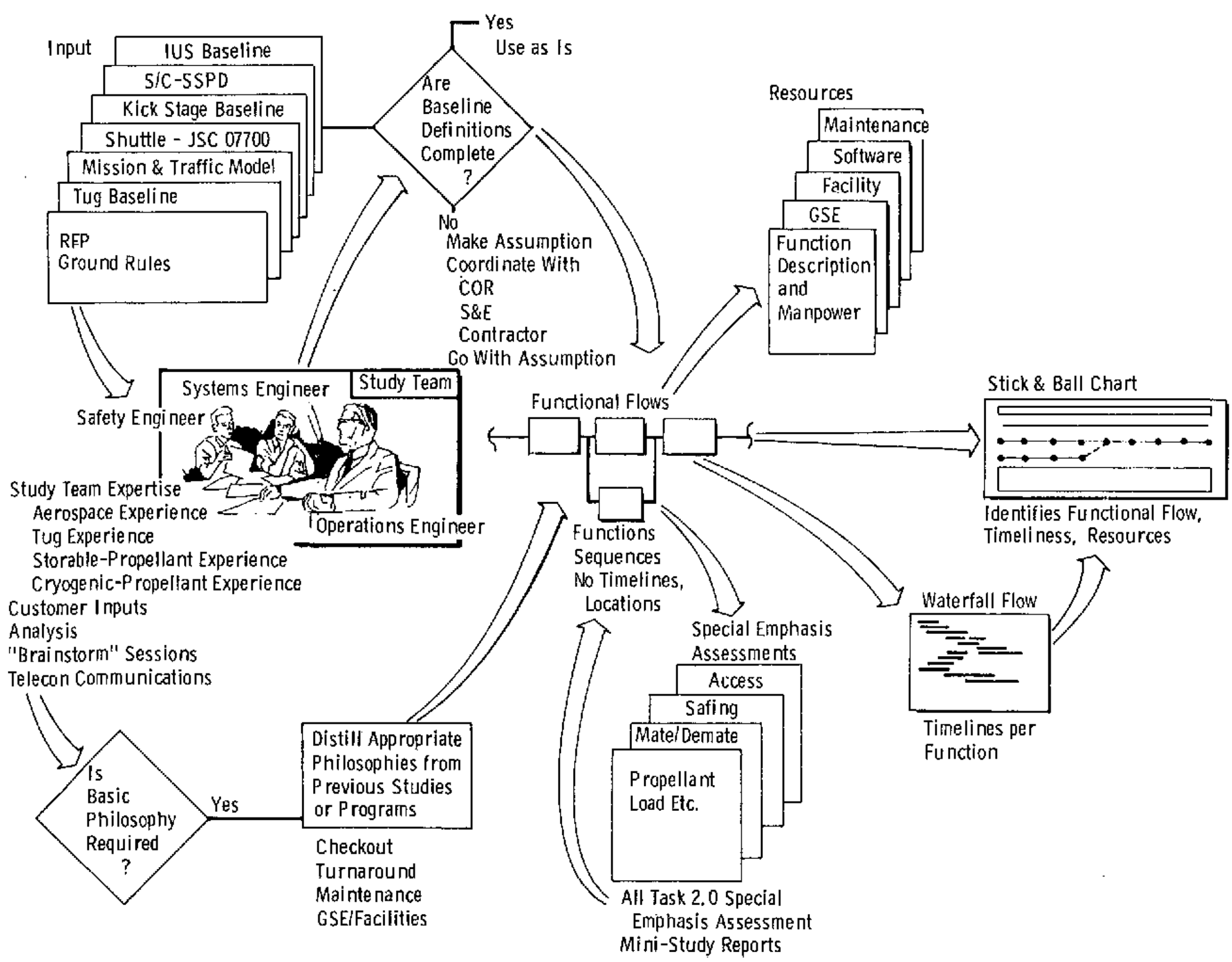


Figure III-1 Ground Operations Methodology

The primary input data was the Space Tug Baseline Document, 68M00039, Volumes 1 through 4, and the reference information on IUS and kick stage configurations. Because the subject of this task was ground operations, Volume 4 of the Tug Baseline (operations) was treated as a point of departure only, not as firm requirements. The source document for payload element descriptions was the current SSPD data. With NASA concurrence, the January 1974 traffic model was used at the beginning of the study for flight manifest, payload combinations, flight frequencies, and retrieval missions. However, it became apparent that the existing traffic model was inadequate for fleet and resource sizing. The January 1974 model is based on a different Tug than the current baseline, has not incorporated the most recent DOD traffic estimates, and did not include the latest updated SSPD data. A Tug-unique traffic model was provided by NASA for use on this study. The traffic is summarized on Figure III-2.

Source	MMC Data	MSFC/MDAC Data			IUS Data from MSFC NASA/DOD Data from MMC Extrapolation for IUS Tug Data from MSFC/MDAC								
Year / Configuration	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Total
Expendable IUS - No Transition with Tug NASA - ETR Only DOD - ETR Only	9 8 1	16 11 5	14 5 9	17 10 7									56
Expendable IUS - 1 yr Transition with Tug NASA - ETR Only DOD - ETR Only	9 8 1	16 11 5	14 5 9	17 10 7	7 5 2								63
Expendable IUS - IUS Used Through 1991 NASA - ETR Only DOD - ETR Only	9 8 1	16 11 5	14 5 9	17 10 7	7 5 2	4 2 2	3 1 2	1 0 1	1 0 1	2 0 2	1 0 1	1 0 1	76
Tug - No IUS Transition NASA - ETR/WTR DOD - ETR Only					19 13/2 4	22 11/1 10	24 15/2 7	18 12/1 5	18 11/1 6	16 11/1 4	26 17/2 7	22 14/1 7	165
Tug - 1-Yr IUS Transition					13	22	24	18	18	16	26	22	159
Tut - Using IUS through 1991					13	19	23	18	18	16	26	22	155

Figure III-2 Study Traffic Model Summary

In some instances, the baseline definition required expansion or had not been developed sufficiently. In those cases, assumptions were established, coordinated with the COR, S&E representatives, and, if applicable, the appropriate on-going study contractor. When agreement was reached, the assumptions were documented and the study proceeded on that basis.

In some areas such as checkout and maintenance concepts, it was necessary to establish basic philosophies before more detailed analysis could be performed. Where the baseline Tug characteristics were compatible with sound philosophies developed in previous Tug studies or NASA documents, they were used. In other instances, modified or new philosophies were developed to be more consistent with the current baseline Tug.

The methodology then followed a relatively traditional functional analysis approach involving development of a functional flow, identification of resource requirements, and completion of a waterfall flow. To supplement and amplify the flows, special emphasis assessments were performed in task 2.0. The results were factored into the flows, as applicable.

This strawman flow was used as a point of departure for the remainder of the study. At appropriate points in the study, optimization trades were performed as shown in Figure III-3, and the results were incorporated into the baseline. The rationale for each decision shown on Figure III-3 is discussed in the appropriate section of this report.

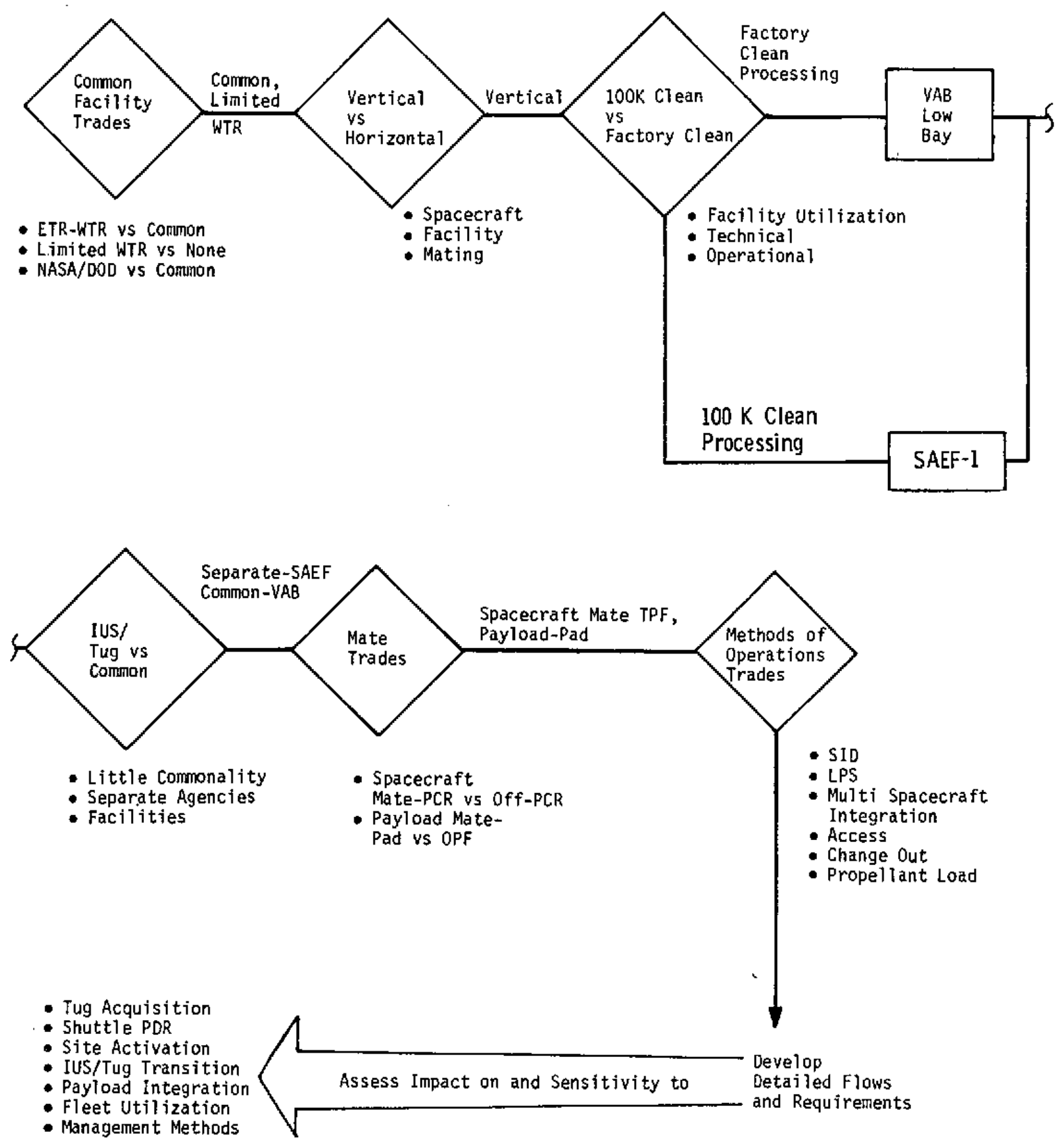


Figure III-3 Processing Flow Optimization Trades

The resultant baseline processing flow is shown on Figure III-4. After Orbiter landing and safing on the Orbiter Landing Field (OLF) and payload removal in the Orbiter Processing Facility (OPF), the Tug is moved to the Tug Processing Facility (TPF) where refurbishment, checkout, and Tug/spacecraft mate occurs. All processing is performed with the Tug and spacecraft in a vertical orientation. When a kick stage is required, kick stage buildup, checkout, and Tug-kick stage mate also takes place in the TPF. After Tug/spacecraft mate, the Tug APS hypergolic propellants are loaded and pressurants are partially loaded. The payload is then moved to the launch pad and installed in the Payload Changeout Room (PCR). When the Orbiter is ready for payload mate, the PCR is mated to the Orbiter, the PCR and Orbiter doors opened, and the payload installed in and mated to the Orbiter. Interface tests are then performed, fuel cell reactants and remaining pressurants loaded, and at T-2 hours, MPS propellants loaded concurrent with Shuttle cryogenic propellant loading.

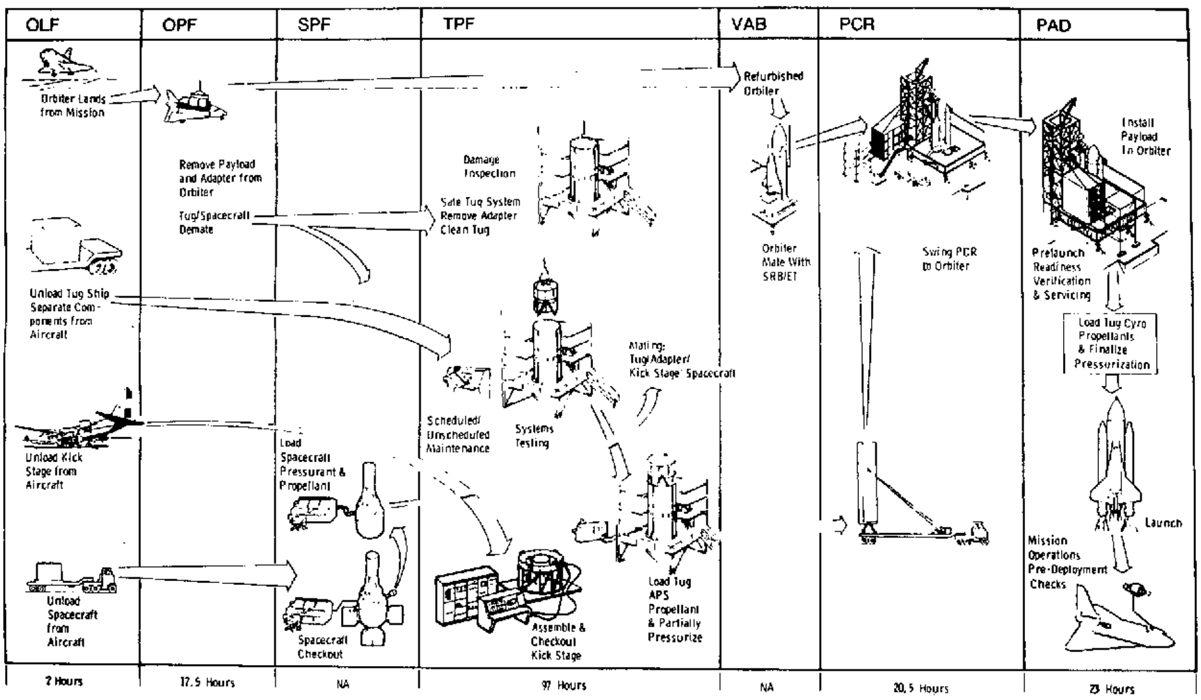


Figure III-4 Tug Ground Operations Flow

This Tug processing flow requires 157 hours from Orbiter landing to Orbiter liftoff. In addition, the flow reflects 3 hours stand-by time while other operations are in progress. Of this time, the Tug is on the OLF for 2 hours, in the OPF for 14½ hours and in the TPF for 100 hours. Movement to the pad, installation in the PCR, and Tug standby required 20½ hours. The payload is installed in the Orbiter at T-23 hours. The crew size to perform these operations for one Tug cycle on a 2-shift basis is 80 personnel.

This organization of 80 people considers times of peak work loads and slack time. During periods of slack time, operations personnel would be involved in off-line refurbishment, checkout, and calibration of flight components and GSE units. During periods of peak Tug activities, facility support personnel will supplement test operations personnel. The total operations crew to support the Tug fleet and to accommodate the mission model is discussed in the fleet utilization section.

Some of the more salient features of our processing flow are shown in Table III-1. A common Tug maintenance and checkout facility was recommended over equal and dedicated ETR and WTR facilities. The study shows significant savings in this approach if the WTR Tug traffic is low. The traffic model provided by NASA for use on this study shows the WTR Tug traffic averaging only one a year, with two flights per year shown in only three years of the period. A common NASA/DOD processing facility for the Tug was recommended over dedicated facilities. This does not necessarily imply common Tug/IUS facilities. If the Tug is processed in the VAB, joint IUS/Tug facilities are possible; however, if the Tug is processed in the SAEF-1 facility, separate IUS facilities must be provided because of space limitations. The combined DOD/NASA flight density does not preclude common Tug processing. Although the full impact of classified payloads have not been assessed, it is assumed that they can be handled in a common area if properly planned.

Table III-1 Salient Features of Tug Processing Flow

Common Tug Processing Facility (ETR/WTR)
Common NASA and DOD Tug Processing Facility
Tug-to-Spacecraft Mate Off Pad (ETR), WTR Delta
Payload-to-Orbiter Mate On Pad
The Spacecraft Is Assumed Flight Ready when Received for Tug-to-Spacecraft Integration
Multiple Spacecraft Integration Is Performed Off-Tug
Tug-to-Spacecraft Mate and Processing Is Vertical
Checkout Based on "Last Flight Is Best Test" Philosophy
LPS Is Primary Mode of Ground Checkout
Interface Verification Is Performed in TPF Cell (Built-in Simulation)

The study recommends Tug to spacecraft mating and integration off-pad at ETR. The heavy traffic precludes routine mating at the pad; however, the option of integration at the PCR should be provided for priority payload changeout and for contingencies. At WTR, the traffic is much lighter and the facilities are being designed with greater flexibility because only one launch pad is available. Consequently, the study recommends a WTR delta of integration and checkout in the PPR/PCR.

For Tug payloads, integration into the Shuttle should be performed vertically at the pad rather than horizontally at the OPF. This saves approximately 60 hours on each Tug turnaround cycle. In addition, it accommodates the spacecraft that cannot be handled in a horizontal attitude.

Multiple spacecraft integration should be performed off-Tug. A current study indicates that on-line multiple spacecraft integration could add between 20 and 30 hours of serial processing time to the Tug flow. Although not critical when only minimal flow is considered, combinations of factors such as excessive maintenance times or high checkout and processing failures could increase the turnaround time to the point where additional resources of processing channels or sets of GSE might be required.

The baseline flow recommends that off-Orbiter level I integration be performed in the processing cell rather than in a separate integration facility. This approach is further discussed in payload integration task 4.0.

B. SPECIAL EMPHASIS ASSESSMENTS (TASK 2.0)

The study plan required analysis to a greater level of detail in certain selected emphasis areas in order to drive out specific requirements. In other instances, it becomes evident in performing the study that additional analysis would be required to provide sufficient data upon which to base operational tradeoff decisions. The results of these assessments were incorporated into the baseline processing requirements where appropriate. In addition, when warranted, a study report was prepared to document the rationale and derivation of results.

1.0 Tug Postlanding Safing

During flight operations, the Tug contains energy sources that constitute potential hazards but are required for mission accomplishment. These potential hazards have been reduced to an acceptable level for flight operation by design features, safety factors, and by providing for the control of the energy sources. The Tug safing philosophy is to eliminate each energy source as soon as practical after the mission requirements for that energy is completed. Residual energy sources (hazards) must, of course, remain under monitor and control.

Tug safing, therefore, is actually accomplished incrementally during recovery, reentry, and postlanding operations. It may be assumed that the first two sets of safing actions listed on Figure III-5 will be accomplished before Orbiter reentry and landing. Postlanding safing considerations include operations with the Tug in the Orbiter payload bay and after removal. For normal turnaround operations, hazards will be reduced to a level of acceptance for personnel access and performance of required activities. It is considered neither essential nor practical to achieve an absolute safe (completely inert) Tug status.

Incremental Tug Safing to Eliminate/Reduce Energy Sources as Mission Permits

Monitor and Control Any Residual Hazards

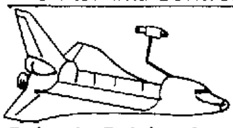
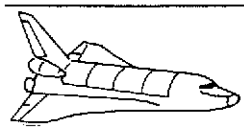
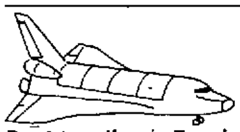
 Prior to Retrieval	Main Propellants Vented
 Prior to Re-Entry	APS Secured Tug/Orbiter Interfaces Verified Tug Electrical Power Sources Put On Standby Tug Electrical Power Supplied by Orbiter Fuel Cell Reactants Vented
 Post Landing - Tug in Orbiter	Orbiter Crew Requirements (OLF) Ground Control (OLF) Control Tank Pressure, Integrity Verification, Purge Hazardous Vapor Detection Ground Crew (OPF) H_2 Vent to Burn Stack
 Prior to Maintenance	Remove Hydrazine Residuals (TPF) Remove Auxiliary Battery (TPF) Verify Integrity Pressure System (TPF) Decay Leak, Vent to ≥ 4 Safety Factor H_2 Vent to Burn Stack, Lock Up Blanket Pressure Monitor Pressure Via LPS

Figure III-5 Tug Postlanding Safing Philosophy

The Tug systems status at landing provides the basis for developing postlanding safing requirements. Based on assumed prelanding safing actions, the following Tug potential hazards may be present upon Orbiter landing.

Chemical energy in the form of residual hydrogen vapor and hydrazine will be present. The liquid hydrogen residuals will have been expelled from the main propellant and fuel cell reactant tanks on orbit. Previous studies have shown that the tanks can only be evacuated to ~2 psi (1.38×10^4 N/m^2) while on orbit rather than to vacuum. This is due to the risk of hydrogen approaching its triple point. Consequently, same residual vapor will remain. The APS will be secured by closing the series redundant thruster valves with residual hydrazine in the tank and lines.

Pressure energy will be present in the main propellant tanks, fuel cell reactant tanks, and the pressurization systems. Before entry, the main propellant tanks will be pressurized to a level to preclude implosion during landing. The pressurization systems will contain residual pressurants. These pressures will vary as a function of temperature changes during and after landing.

The partially discharged auxiliary (flight) battery presents an electrical energy source. Since no ordnance devices have been identified in the baseline configuration, safing requirements for ordnance systems have not been included in the safing study.

The safing requirements during Orbiter/Tug (Tug in Orbiter payload bay) operations will be discussed in the following three functional areas:

1) The Orbiter flight crew, having prime responsibility to monitor and control safety critical Tug functions, will make a final check to ensure all Caution and Warning (C&W) parameters are within limits before egress. The flight crew will also initiate and verify the transfer of control of Tug functions to Ground Control.

2) The Tug Ground Control will monitor the C&W parameters with particular attention to tank pressure levels during post-landing temperature variations. In the course of monitoring tank pressures and temperatures, Ground Control will verify the pressure integrity of all tanks in the gross terms available with flight instrumentation. These first two sets of requirements will be accomplished at the OLF.

3) The Orbiter Ground Operations Crew will establish the payload bay purge to neutralize any hazardous vapors. The exhaust from the payload bay purge will be subjected to hazardous vapor detectors to ensure freedom from leaks. In the event the hydrogen tanks require venting, the Tug H_2 vent will be connected to a burn stack via the Orbiter. These operations are performed in the OPF.

The Tug safing for turnaround operations is completed after removal from the Orbiter payload bay and transport to the TPF airlock. The following four requirements were established to reduce hazards to an acceptable level for turnaround activities:

1) The APS tanks and lines will be drained of residual liquid hydrazine. The system will then be purged and sealed with a dry nitrogen blanket.

2) The auxiliary (flight) battery will be disconnected and removed from the Tug.

3) All Tug pressurized systems will be leak checked with helium at maximum operating pressure to verify systems integrity. Upon completion of the leak check, each system will be vented to a pressure of one-fourth or less of the design burst pressure and sealed. Hydrogen systems will be vented to a pressure of one-fourth or less of the design burst pressure and sealed.

Hydrogen systems will be vented to a burn stack for disposal of any residual hydrogen vapor when reducing to the one-fourth design proof level. The remainder of processing will be accomplished with the tanks locked up to this blanket pressure.

4) Pressure systems will be monitored by the LPS during turnaround activities to ensure that pressure levels remain in limits. Continuous monitoring is not required since pressure changes are a function of temperature change and the Tug is in a controlled environment during turnaround. A temperature change of 30°F (16.7°C) would produce a pressure change in the order of 1 psia (6.89×10^3 N/m^2) on the largest (hydrogen) tank.

2.0 Tug/Shuttle Mating and Demating Functions and Constraints

The objective of this special emphasis assessment was to determine the mate/demate functions associated with payload installation on the pad using the PCR and to identify any problems or constraints associated with those functions.

Figure III-6 shows the steps in the mate/demate process. The illustrations in the center show the PCR in a retracted position, a payload on the PCR manipulator, and the PCR extended to the Orbiter, respectively.

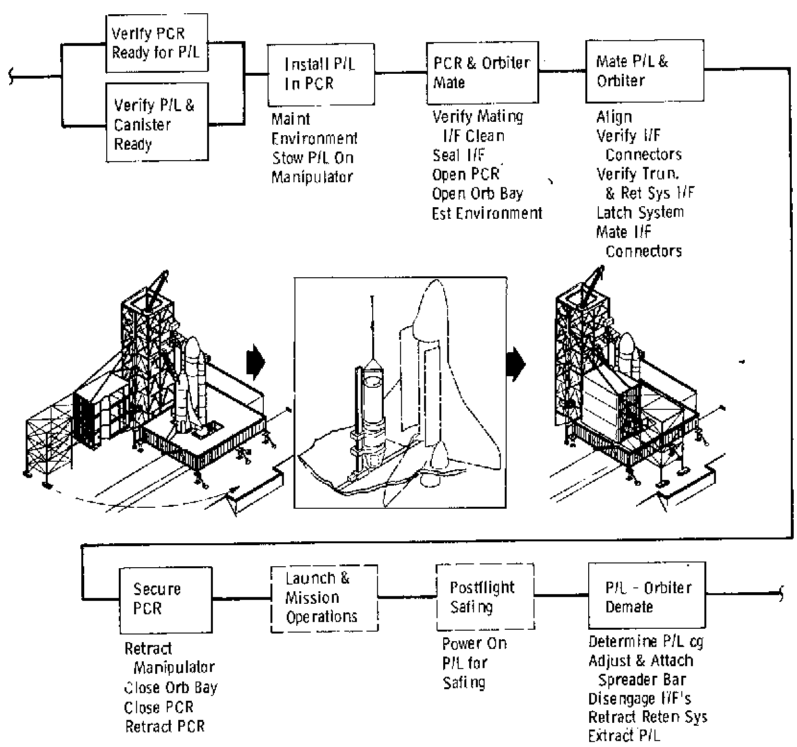


Figure III-6 Tug/Shuttle Mate/Demate Functions

In the process of assessing the mate/demate functions, four significant areas of concern were identified; at the completion of this study, one area has been resolved, two are being investigated by other contractors/NASA, and one will require further attention in later phases of the Tug development. These areas of concern are:

1) Additional hard points required - when the steps involved in installation of the Tug into the cargo bay were analyzed, it became apparent that there is no way to transfer from the PCR manipulator to the cargo bay retention points because there is only one set of hard points at each location on the Tug. This inadequacy was presented in September and both NASA-KSC and the GDC-Interface study have assessed the problem and presented alternative solutions. KSC recommended a second set of standard handling hard points that could be removed before flight. GDC recommended a modificaton to the existing hard point attachments to allow ground handling manipulators to be used inboard of the retention hard points that mate with the Orbiter.

2) No Orbiter hard point - The baseline Tug configuration defines two retention points at Sta 1293. There is no corresponding hard point in the Orbiter at Sta 1293. This discrepancy was presented in the first data exchange. Since then several potential solutions have been presented including moving the retention point to Sta 1246.

3) Limited access - both the mate/demate assessment and the access assessment identified marginal access in the area behind the engine compartment when in the cargo bay. Access to connect the electrical and fluid umbilicals to the service panels located on the Orbiter aft bulkhead between Sta $Z_o 350$ and $Z_o 360$ is very limited, if not impossible. Potential resolutions to this concern have been presented and will be discussed in the access study summary.

4) CG determination - the baseline Tug configuration has a tight clearance between the aft end of the deployment adapter and the cargo bay aft bulkhead. This clearance could be as small as inches. If a full size payload is retrieved, the clearance at the forward end could also be critical when removing the payload from the cargo bay. Although the cg of the Tug and delivery spacecraft would be known precisely at liftoff, both the Tug and the spacecraft to be retrieved will have expended some consumables, providing some uncertainties in the cg location. For removal, the payload is translated out of the cargo bay using a crane, sling, and spreader bars. To preclude any swinging of the payload when initially lifted, the cg must be known precisely to adjust the spreader bars before

lifting. At the present time, the design of the Tug has not matured enough to determine if flight instrumentation can provide the data required to determine the cg.

3.0 Tug Access Assessment

An access assessment was performed on the Tug to determine ease of operations and maintainability of the baseline configuration. Ground rules and assumptions on which the assessment was based are shown in first block of Figure III-8. The next block shows the types and definitions of access that were considered. These were:

1) Physical - access related to physical accessibility, or the ability to remove and replace those items considered LRUs.

2) Functional - access related to ability to perform reverification of replaced LRUs and accomplishment of subsystem/system checkout and health monitoring.

3) Service - access related to loading of mission required consumables, and safing at the time of Tug retrieval and before Tug refurbishment.

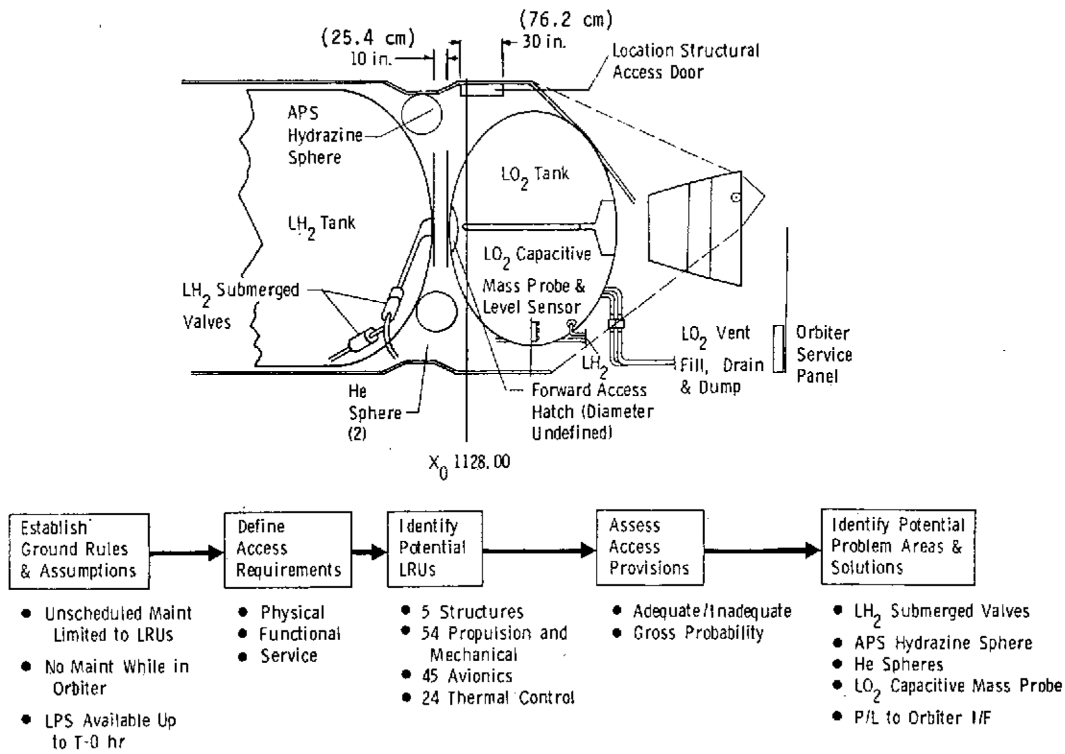


Figure III-7 Access Assessment Results

Before starting the access evaluations, it was also necessary to complete an extensive study of the baseline configuration to determine which types of black boxes and/or components would be considered as candidate LRUs. The results of this study are contained in the final report and are, in general, as follows: 5 structural, 54 propulsion and mechanical, 24 thermal control, and 45 avionics LRUs. Such things as size, weight, location, and probability of failure were considered in the selection of candidate LRUs. The relatively high number of candidate LRUs is due to the inability to "paletize" or package LRUs in the area available on the basline configuration (forward skirt and intertank areas).

After selection of the LRUs, each candidate was evaluated for physical access in accordance with its proximity to baseline configuration access provisions. An assessment of adequacy was established. Of the 128 LRUs identified, 4 demonstrated access problems. Upon completion of the LRU physical access evaluation, the baseline configuration was analyzed with relation to the Tug functional flow diagram. This analysis considered each functional block and the feasibility of accomplishing the required activities within the constraints of the defined configuration. This analysis yielded one functional and service problem.

The five significant access problems are:

1) LH_2 submerged valves - The LH_2 dump, fill, drain, and prevalves are submerged primarily to reduce the risk of leakage and to help reduce thermal leakage problems. The LH_2 provides an extremely severe thermal environment for these critical valves. In event of a failure, replacement accessibility is inadequate. Three potential solutions were provided: move the valves to the exterior, increase the diameter of the forward dome hatch and constrain slosh baffling design, or add an aft dome access hatch.

2) APS hydrazine sphere and He spheres - There is a 30 in. (76.2 cm) structural access door provided approximately at Sta 1128. The hydrazine sphere is calculated to be approximately 32 in. (81.3 cm) in diameter. The probability of a failure of the bladder due to long term exposure to hydrazine is relatively high. The He spheres are approximately 29 in. (73.7 cm) in diameter. Three potential solutions were presented: increase the access door to 36 in. (91.4 cm) with the attendant weight penalty for doubling, increase the quantity and reduce the size of spheres, or implement the optional field splice at STA 1061.74. Since the latter also solves the next problem, it is the favored solution.

3) LO_2 capacitive mass probe and level sensors - Although a small access hatch is provided in the forward dome, there is only 10 in. (25.4 cm) clearance between the aft dome of the LH_2 tank and the access hatch on the LO_2 tank forward dome. Several potential solutions were presented. Implementation of the optional field splice at Sta 1061.74 is recommended since it solves several problems.

4) Payload to Orbiter interface - Access is required to the service panels presently located at the bottom of the cargo bay on the aft bulkhead between Sta $Z_o 350$ and $Z_o 360$. When the Tug is in place in the cargo bay, the engine bell and deployment adapter makes access to the panels to connect fluid and electrical umbilicals very marginal. Several potential solutions are being considered. The study recommended moving the service panels above the center line to Sta $Z_o 440$. The GDC interface study is evaluating another configuration deployment adapter that improves but does not eliminate the access problem.

4.0 Payload Changeout at the Pad Assessment

Figure III-8 illustrates the functional flow for four options of payload changeout. The top flow illustrates changeout of a spacecraft using two approaches: (1) leave the Tug in the cargo bay, or (2) remove the Tug/spacecraft to the PCR for spacecraft changeout in the PCR. The bottom flow shows changout of the entire payload or of the Tug only. Payload changeout was considered under three time related conditions: before loading fuel cell reactants (T-10 hr), before loading cryogenic propellants and flight pressures (T-2 hr), and after cryogenic propellant loading (T-45 min). In each case, the entire vehicle must be safed before initiating the change.

Depending on the time of occurrence of payload changeout, the impact on Shuttle can be almost zero before fuel cell reactant loading at T-10 hr to extensive after MPS loading at T-45 min.

If propellants have been loaded in the ET, safety dictates they be unloaded and purged before initiating payload changeout. The fuel cell reactant tanks should be unloaded and purged because the reactant tanks are below the Orbiter bay per Rockwell International SSV73-66, November 1973. They represent a hazard to personnel and equipment in the vicinity during changeout.

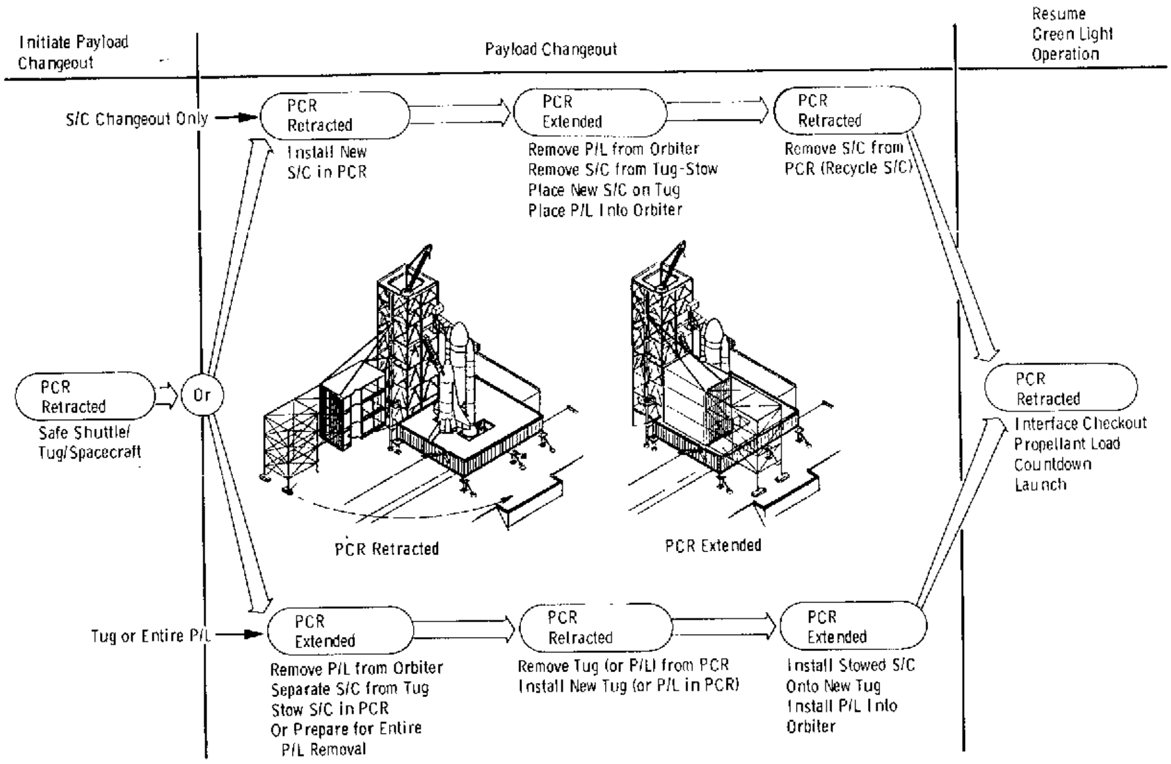


Figure III-8 Payload Changeout Functional Flow

All ordnance devices should be electrically safed and all ordnance buses deenergized until the resumption of green light activities. Dedicated buses to all Shuttle energy subsystems such as pressurization and propulsion systems should also be deactivated. Before deactivation, all high pressure storage devices should be reduced in pressure to levels consistent with general personnel access in the vicinity.

A spacecraft changeout requires the Orbiter bay doors to be cycled open/closed. A Tug or entire payload change requires the open/closed cycle to be performed twice. Each cycle will impose the attendant environmental stabilization sequence on the Orbiter bay and PCR temperature, humidity, air flow, and particle count.

In addition to the impact on the Orbiter, certain requirements are imposed on the payloads to facilitate changeout. These delta requirements follow.

1) GSE - The green light GSE will be sufficient to accommodate changeout. This is true because the PCR operation is capable of mating and integrating a Tug and spacecraft as one green light option or handling a mated Tug and spacecraft as another option. Those two conditions cover the full spectrum of changeouts as far as GSE is concerned.

2) Facility - The only facility impact is an additional requirement on the PCR, which allows temporary stowage of two spacecraft in the PCR simultaneously while either changing a spacecraft or a Tug, and which allows access to the spacecraft in the Orbiter bay. These two requirements will save a PCR retraction/extension cycle in spacecraft changeout and allow the Tug to remain inside the Orbiter bay for some spacecraft with small diameters and lengths.

3) Timelines - Payload changeout can range from 11 to 20 hours to get back to a green light condition and can add 28 to 42 hours to the launch schedule depending on whether the spacecraft, Tug, or entire payload is changed out.

4) Software - The LPS will require programming to control the safing functions in the Shuttle/Tug and spacecraft including propellant unloading, pressure reduction, fuel cell reactant unloading purging, electrical power switching, and energy system safing. While these programs are not a normal part of a green light flow, they are needed for contingencies so they are not unique to changeout.

When coupled with the contingency analysis performed under task 3.0, the conclusions of this assessment are that all four changeout alternatives should be provided for in the planning and facilities provisions for the Tug. Under certain situations, it might be necessary to implement any one of the following options:

1) Spacecraft changeout leaving the Tug in the cargo bay;

2) Spacecraft changeout with Tug/spacecraft separation in the PCR (Tug removed from cargo bay);

3) Entire payload (Tug and spacecraft) changeout;

4) Tug only changeout.

5.0 Propellant and Pressurant System Assessment

The propellant loading system assessment evaluated three areas: adequacy of the baseline system from an operational point of view, operational timelines, and safety considerations. As an example of a baseline system assessment, Figure III-9 illustrates the recommended modifications to the APS hydrazine system to enhance operations. These recommended modifications include:

1) A servicing port between the series valves ahead of each thruster to provide for functional and leak check of each valve. Without this provision, it is possible to start a mission with leakage in one of the two series-redundant valves.

This capability also provides an effective way to purge the system as required without contaminating the catalyst bed of the thruster.

2) Solenoid valves, plus a quick disconnect and cap, are recommended for pressurant servicing of the He spheres and the N_2H_4 bladder tanks (two places) to provide series isolation at the servicing connections. The pressure regulator in the ground servicing fill connection should be deleted.

3) Isolation valves are recommended between the helium storage tank and the pressure regulators to accommodate concurrent hydrazine and helium loading. During loading of the APS propellant tanks, helium must first be applied to bottom the bladder in the tank, then vented as the liquid displaces the helium gas during fill. The isolation valves allow loading of hydrazine and helium concurrently, and allow the flight pressurization of the propellant tanks to be delayed until the final count, or later.

A similar assessment was performed on the He pressurant system, the fuel cell reactant system, the MLI purge system, and the main propulsion system.

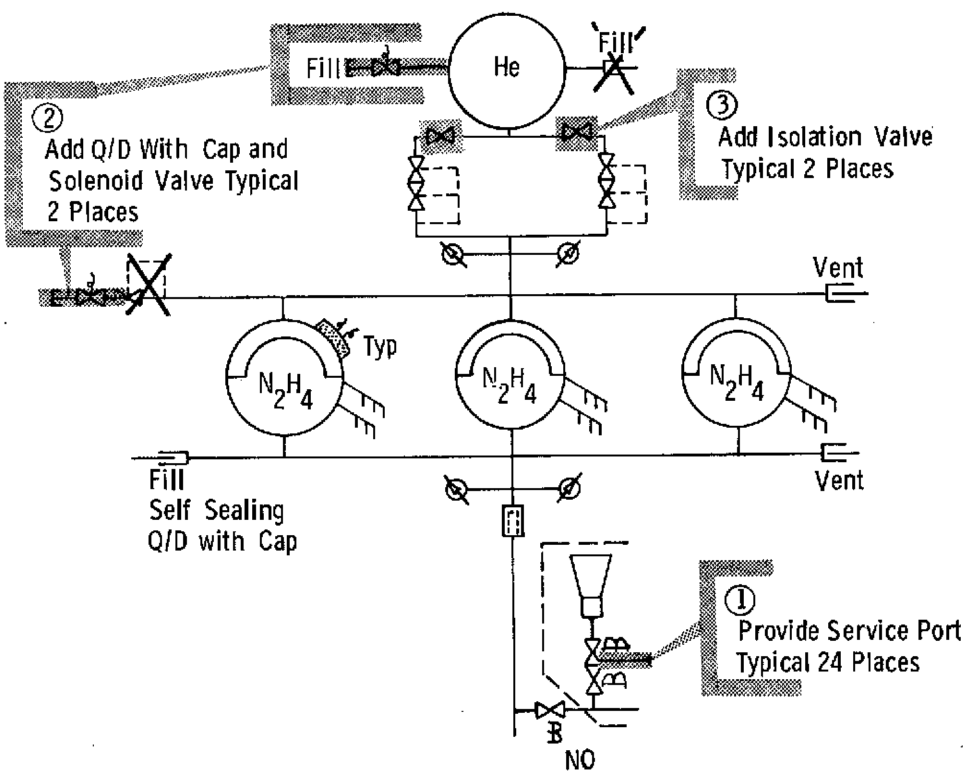


Figure III-9 Tug APS Recommended Modifications

Figure III-10 is a timeline assessment performed on the main propellant system. A similar assessment was performed on other propellant and pressurant systems. The Tug main propellant system will be loaded with cryogenics concurrently with the loading of the Shuttle cryogenics. This will be accomplished on-pad with the Shuttle loading starting at T-2 hours and requiring 75 minutes for completion. The Tug loading will be accomplished within this time span as shown. Tug loading sequence is dependent on the Shuttle loading sequence and cannot be finalized until the Shuttle loading sequence is totally defined. The Shuttle loading sequence shown is based on previous studies performed for NASA and updated to reflect current loading requirements of 75 minutes for the External Tanks.

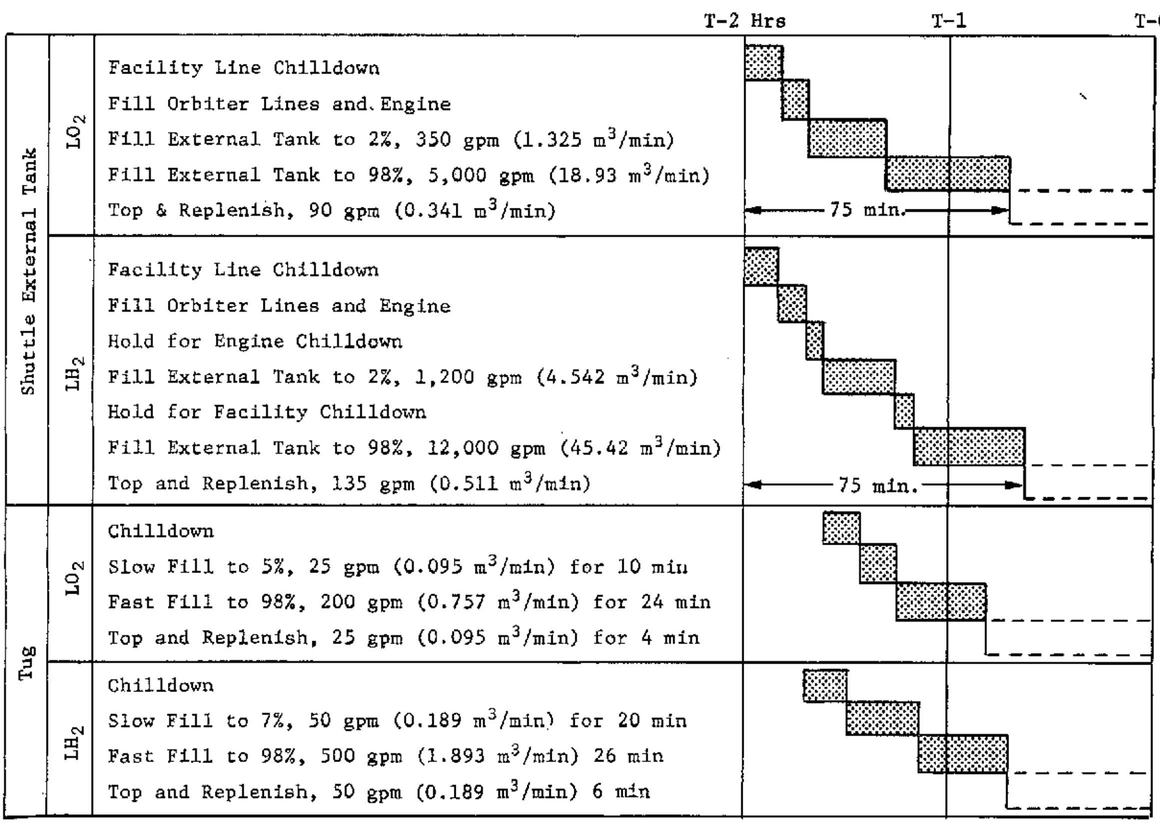


Figure III-10 Simultaneous Shuttle/Tug Propellant Loading

The Tug loading sequence is arranged such that the Tug flow starts after Shuttle flow is initiated and stops before the Shuttle flow is terminated. Each event for Shuttle and Tug loadings is scheduled so as not to happen simultaneously with another loading event. This will provide maximum operational visibility and maximize the safety considerations.

Finally, the propellant loading operations were optimized with respect to safety. The resulting operations and their safety considerations are summarized on Table III-2.

Table III-2 Propellant Loading Safety Aspects

Auxiliary Propulsion System
Load Propellant in TPF
Best Loading Area Control
Complete Post Loading Leak Check
Contained Storable Propellant Acceptable
Handling Weight Increase with Propellant (∿ 10%) Acceptable
Pressurants
Partial Load in TPF - Final on Pad
Maintain Safety Factor ≥ 4.0 for Handling
Minimizes Tank Heating Stresses
Fuel Cell Reactants
Load on Pad T-10 hours
Orbiter - Tug Sequentially
Reactants Initiated Sequentially
MLI Purge
Dedicated Purge Vent
Propellant Vapors Vented Overboard
No Back Pressure Imposed on Purge Bag
Main Propulsion System
Tug Loading Lines Separate from Orbiter
ET Static Head and Surges Precluded
Simultaneous Drain ET and Tug

The auxiliary propulsion system propellant, hydrazine (N_2H_4), is stable in a contained system and presents the opportunity to load the system early in launch preparations. Loading in the TPF provides the optimum area control, both personnel access and environmental control including ventilation and decontamination of possible spills. Maximum access is available in the TPF to make a complete postloading leak check of the ACS. Hydrazine is stable to shock and operational temperatures since thermal decomposition begins at about 320°F (160°C) and the critical temperature is 716°F (380°C). The ACS propellant adds a maximum of 500 lb (226.8 kg) approximately 10%, to the Tug dry handling weight. This does not increase the hazards of handling appreciably and is considered acceptable.

The recommended two-step pressurant loading enhances operational safety. Partial pressurization in the TPF and final pressurization at the pad assures thermal stabilization and minimizes

stresses on the airborne tank during final loading. Limiting the partial pressurization to provide a safety factor ≥ 4.0 ensures adequate safety during handling and transportation.

Loading the Orbiter and Tug fuel cell reactants sequentially provides minimum personnel access constraints at the pad for hazardous operations. The hazards associated with reactant transfers are minimized by starting the LO_2 and LH_2 transfers sequentially.

Providing a dedicated MLI purge vent enhances safe operation and eliminates possible contamination of the Orbiter bay with helium. The vapors are vented safely overboard. The dedicated vent also precludes possible damage to the purge bag from back pressure from main tank GO_2 or GH_2 vents.

The recommended separate Tug main propellant loading lines provide optimum safety within the constraints of simultaneous loading. Separate lines positively prevent imposing ET propellant static head pressure or ET loading pressure surges on Tug tanks. Launch pad emergencies during and after propellant loading can be counteracted more readily with separate lines.

6.0 Minimum WTR Launch Capability

Early in the study, a common Tug maintenance and checkout facility at ETR was selected over full and redundant facilities at both ETR and WTR. In this concept, fully refurbished and checked out Tugs would be ferried to WTR for those missions requiring a WTR launch. WTR would have launch capability but no Tug maintenance and processing facilities. Significant savings in facilities and manpower can be realized with this approach.

However, the WTR Tug traffic has changed significantly in the past year, as illustrated by Table III-3. The second model shown represents the October 1973 NASA model published in January 1974. In March 1974 a new DOD model that did not show any DOD Tug flights out of WTR was published. The third model shown represents the DOD model integrated into the NASA model. The September 1974 data, the information provided by MSFC for use of this study, reflect an average of one Tug flight per year out of WTR with two flights per year shown only in 1984, 1986, and 1990.

With the continued decline in WTR Tug traffic, the obvious question was, is it worth it to have any Tug launch capability at WTR? The objective of this assessment was to answer that question.

Table III-3 WTR Tug Traffic Evolution

	84	85	86	87	88	89	90	91	Annual Average
Summer 73									
NASA	4	6	4	6	4	6	4	--	
DOD	9	7	13	8	12	8	8	--	
Total	13	13	17	14	16	14	12	--	14
January 74									
NASA	4	1	1	2	2	2	2	2	
DOD	4	5	4	4	3	5	3	5	
Total	8	6	5	6	5	7	5	7	6
March 74									
NASA	4	1	1	2	2	2	2	2	
DOD	0	0	0	0	0	0	0	0	
Total	4	1	1	2	2	2	2	2	2
September 74									
NASA	2	1	2	1	1	1	2	1	
DOD	0	0	0	0	0	0	0	0	
Total	2	1	2	1	1	1	2	1	1

As a starting point, it was necessary to determine if it is feasible to fly the Tug missions presently identified for WTR out of ETR. Table III-5 shows that, when the traffic model for 1984-1991 is further analyzed, a compliment of only three payloads make up the WTR traffic. All three could be flown out of ETR using a 57-deg (0.9947-rad) inclination. However, only the Upper Atmosphere Explorer can be flown from ETR without penalty. Both the Tiros and Environmental Monitoring Satellite require a kick stage for delivery from ETR. In addition, neither can be recovered from ETR.

Consequently, both EO-12 and EO-56 must be replaced if WTR launch capability is not provided since they cannot be retrieved from ETR. Figure III-14 compares the replacement cost if flown from ETR, with the refurbishment cost if flown and retrieved from WTR. In addition, the price of kick stages required for the delivery of EO-12 and EO-56 from ETR are shown. The cost for spacecraft refurbishment or replacement was obtained from the MDAC study. This comparison shows that the net mission cost without WTR launch capability is $\approx$ \$109M.

Table III-4 WTR Tug Missions Flown from ETR

CURRENT NASA WTR MISSIONS REQUIRING TUG	Traffic - 84-91		ETR Alternate (57° Inclination)	
	Up	Down	Deliver	Retrieve
Environmental Monitoring NN/D (EO-56) 900 x 900 n mi at 103° (1666.8 x 1,666.8 km at 1.797 rad) 4860 lb (2204.5 kg)	6	5	OK*	No
Tiros EO-6 (EO-12) 900 x 900 n mi at 103° (1666.8 x 1666.8 km at 1.797 rad) 4740 lb [4812/4786] (2150.06 kg [2182.72/2170.93])	1	1	OK*	No
Explorer-Upper Atmosphere PHY-1B(AP-01) 140 x 1900 n mi at 90° (259.3 x 3518 km at 1.571 rad) 2004 lb [2060/1674] (909.0 kg [934.42/759.33])	2	2	OK	OK

*Kick Stage Required

DELTA MISSION COSTS

Delta Cost = $137 M + $6.5 M - $34.5 M = $109 M

WTR

Spacecraft	Unit Cost to Refurb	Quantity	Refurb Cost
EO-12	$6 M	1	$6 M
EO-56	$5.7 M	5	$28.5 M
		Total	$34.5 M

ETR

Spacecraft	Unit Cost to Repl	Quantity	Repl Cost	Unit Cost Kick Stage	Quantity	Kick Stage Cost
EO-12	$22 M	1	$22 M	$0.93 M	1	$0.9 M
EO-56	$23 M	5	$115 M	$0.93 M	6	$5.6 M
		Total	$137 M		Total	$6.5 M

The cost involved in providing a minimum launch capability at WTR was developed. This cost included GSE required at WTR over and above that required to safe and handle the Tug. Since WTR is considered a contingency landing site, that equipment is required regardless of launch capability. If the GSE was WTR/ETR common only the procurement cost was included. Where the GSE is required only at WTR, both design/development and procurement costs were included. In a similar manner, facility modification for propellant loading and fluid servicing was estimated. These costs were based on incorporating Tug facilities into the initial WTR modification for STS. The cost of a small, permanent crew at WTR and a larger, transient crew from ETR was estimated. Transportation costs for ferrying the Tug from ETR to WTR and back were included.

Table III-5 shows a summary of the delta costs to provide WTR launch capability. This cost was compared with the cost penalty for flying the same missions out of ETR. The conclusion was that the total cost for WTR Tug launch capability is small and that the investment cost is only a small portion of the total cost. The assessment recommends that minimum Tug launch capability be provided in the WTR baseline.

Table III-5 WTR Tug Launch Summary

Summary

ΔCost for WTR Launches

GSE	\$1484 K
Facilities	\$1991 K
Crew	\$1344 K/year x 8 years = \$10,752 K
Transportation	\$ 32 K/R.T. x 11 R.T. = \$ 352 K

Total ΔCost Impact = \$14,579 K (\$2,675 K Nonrecurring and \$11,904 K Recurring)

Mission Impact (Launch from ETR Instead of WTR)

EO-12 (TIROS) and EO-56 (Environmental Monitoring) Cannot Be Retrieved from ETR

ΔMission Costs = \$109,000 K

Delta Cost

Cost Penalty for No WTR Tug Launch Capability = \$94,400 K

Conclusion:

Total Cost of WTR Tug Launch Capability Is Small Compared to Mission Impact (\$14.6 M vs \$109 M)

Investment Cost Is Only A Small Portion of the Total Cost (\$2.7 M vs \$14.6 M)

Recommendations:

Minimal Tug Launch Capability Should be Included in WTR Baseline

7.0 Vertical vs Horizontal Processing

To optimize the baseline flows and recommend a processing facility for the Tug, it was necessary to determine the preferred processing attitude. Since Tug processing must be compatible with and accommodate spacecraft requirements, this assessment considered both the Tug and the spacecraft.

Tug processing does not require either horizontal or vertical orientation. Tug manufacturing, transport, and landing is in the horizontal position, while it is launched in the vertical position. Access to the Tug interior might be easier in the horizontal position, while some maintenance items would be easier in the vertical plane. All Tug transportation, such as contractor to launch site and TPF to launch pad, in the horizontal position is preferred.

While the Tug has no preference for processing in the horizontal or vertical plane, the IUS does. All of the leading IUS candidates prefer vertical processing because of existing GSE and present processing procedures. All transportation for the IUS and the Tug is preferred in the horizontal position.

Preliminary facility layouts show that vertical processing requires less floor space and is less costly. Most KSC facilities have adequate vertical space but floor space is beginning to become scarce. Spacecraft mating to Tug would be less complicated if accomplished in the vertical orientation. One of the factors is ease of aligning spacecraft to Tug.

All launch site processing crew experience is vertical since all present and past stages were processed vertically. IUS to Tug transition would prove more compatible if both were processed in the same orientation.

Table III-6 shows the results of a survey relative to spacecraft mating preferences performed by MDAC at our request. All spacecraft prefer mating in the vertical position. In addition to preferences, there were four spacecraft that required vertical mating because of:

1) bubble entrapment in the hydrazine system (no bladder explusion);

2) "fines" from the catalyst bed migrating out to the thrusters if handled horizontally;

3) a sun shade that cannot be handled horizontally because it cannot support itself in a one-g environment;

4) a long cylindrical solar array on booms that cannot be handled horizontally in a one-g environment.

With attention to design, these problems might be resolved, but it is doubtful if they could be designed to be compatible with both horizontal and vertical processing. For example, the sun shade could probably be designed to support iteself in either a horizontal or vertical attitude without a weight penalty, but the structural beef up to accommodate either attitude would probably result in a weight penalty. In every case, the spacecraft will eventually be oriented vertically for launch.

For Tug-only processing (before spacecraft mate), cost, processing span times, and crew sizes were not significant discriminators. However, transportation to the launch pad after mating in the vertical position does have significant delta cost factors. A vertical transport trailer would have to be developed. The canister would require end openings for vertical loading with a crane , or as an alternative, a facility manipulator similar to the PCR manipulator could be provided. For 100K clean processing, the airlock roof on the SAEF-1 building would have to be raised to facilitate vertical transportation.

Table III-6 Vertical vs Horizontal Processing, Spacecraft-to-Tug Mating

	Spacecraft	Currently Flying	Current Mating Ops		Preferred Mating Ops		Mandatory Mating Ops	
			Horiz	Vert	Horiz	Vert	Horiz	Vert
1	ATS	X		X		X		X
2	CSC	X		X		X		
3	SEOS					X		
4	ATS-EXP					X		
5	CSC-EXP					X		
6	SEOS-EXP					X		
7	AGOES					X		
8	SMS	X		X		X		
9	MJS	X		X		X		
10	DSCS	X		X		X		X
11	FSC	X		X		X		
12	DSP	X		X		X		X
13	DSCS-S					X		
14	DSP-S					X		X

Considerations

- All Currently Flying Spacecraft Are Mated To Their Carrier In Vertical Position
- All Spacecraft Surveyed Prefer Mating In Vertical Position
- At Least Four of Spacecraft Surveyed Demand Mating In Vertical Position

After analyzing the considerations, it was recommended that, when the Tug is separated from the spacecraft, the Tug be processed in the vertical and transported in the horizontal attitude. To support vertical processing, a vertical cell will be required in the TPF. Mating and payload (Tug/spacecraft) processing after mating should be in the vertical position.

At this time, some spacecraft preferences/requirements after mating require vertical transportation. As the Tug prefers horizontal transport, the spacecraft would appear to be driving the Tug toward vertical transportation. As an alternative, those spacecraft that require vertical orientation at all times could be integrated with the Tug in the PCR on an exception basis.

C. REQUIREMENTS FOR PAYLOAD INTEGRATION (TASK 4.0)

A portion of the Tug Fleet and Ground Operations Schedules and Controls study was devoted to an analysis of the payload integration requirements. Physical integration requirements were studied in conjunction with the baseline Tug processing analysis performed in task 1.0. This task concentrated on the analytical and planning integration normally associated with that period of time during the mission planning era after payload flight assignments/schedules have been developed.

1.0 Multiple Payload Integration

Figure III-17 illustrated one of the more significant aspects of analytical integration--treatment of multiple payloads. Approximately 40% of the Tug flights involve multiple payloads combining two or more spacecraft with the Tug and kick stages. Multiple payload missions will require upstream management and analytical integration as well as close coordination during launch site processing. Titan III experience shows a high potential cost per flight for multiple payload integration activity even with standard and simplified interfaces. Previous NASA-contracted studies addressed the issue of who should do multiple spacecraft integration. Four viable candidates were identified:

1) One of the individual payload owner-operators, possibly the dominant one in the case of unequal value or complexity of payloads;

2) The Shuttle owner or operator;

3) Some independent payload integrator;

4) The carrier, such as Spacelab (in this case, the Tug).

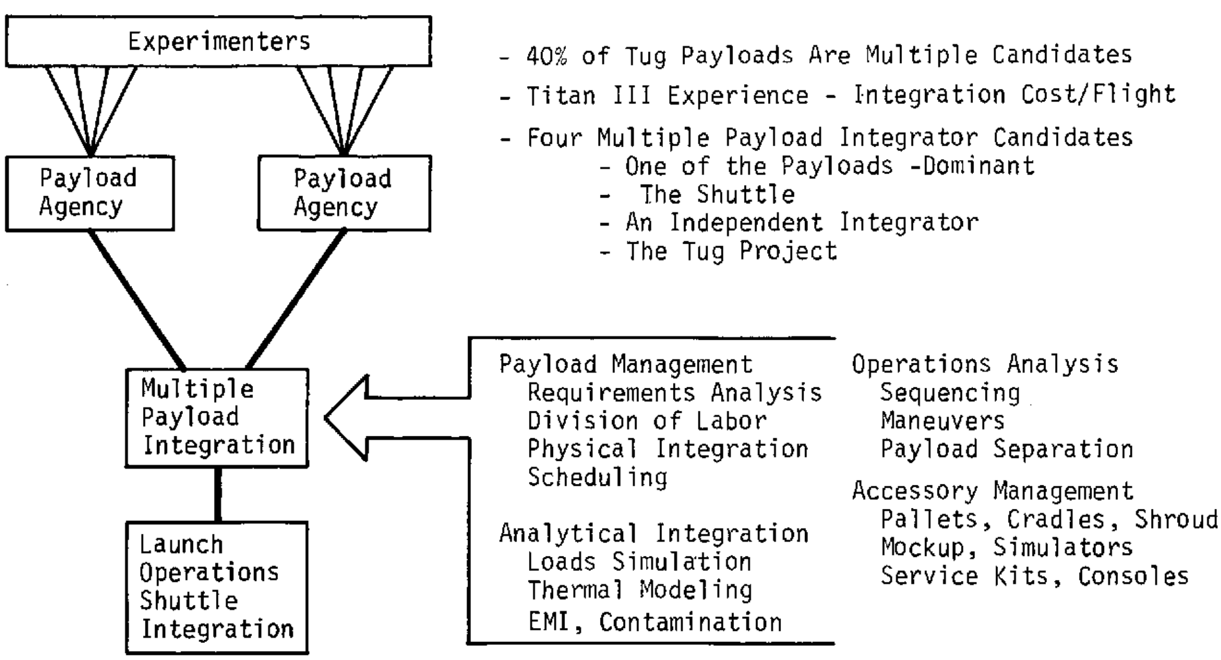


Figure III-11 Multiple Payload Integration

Figure III-12 illustrates the criteria used in that study to assess the four candidates. The results were reassessed to determine the applicability to the Tug. In general, the criteria for evaluation and the results seem to be appropriate.

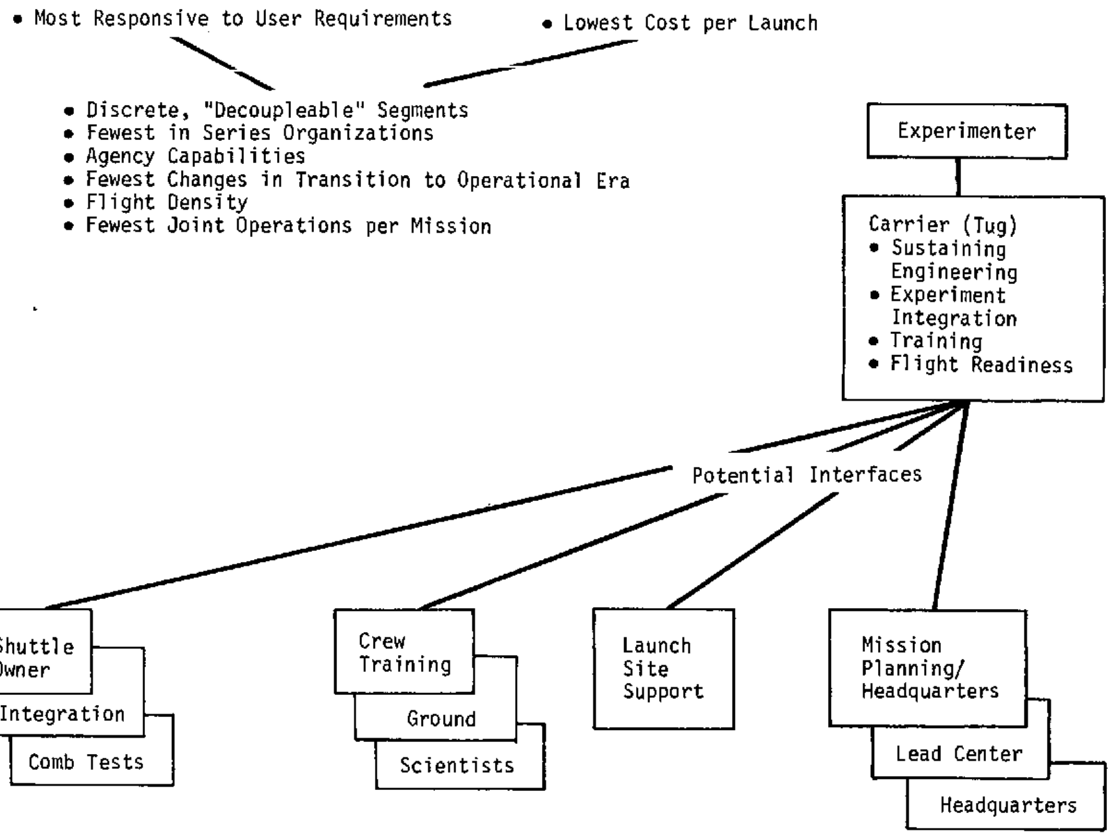


Figure III-12 Criteria for Selection

The conclusion is that either an independent integrator or the carrier (in this case, the Tug) best satisfies the criteria. In either case, it is probable that the Tug project would have those responsibilities early in the program and could at some point relinquish that responsibility to a payload integrator.

Because the present interface concept seems to be moving toward most interfaces between the spacecraft and Orbiter being routed through the Tug, the Tug project appears to be the most logical candidate for multiple payload integration and is the recommendation of this study.

2.0 Level I Integration

Another one of the more significant concerns associated with payload integration is development of a technique for verification of level I integration. Level I integration can be considered in two parts: 1) off-line integrations with the Orbiter using some type of simulation device, and 2) actual integration into the cargo bay. The study addressed the former.

Several previous studies performed by and for NASA-KSC established a set of objectives that should be considered when evaluating various techniques for off-line interface verification. Not all of the objectives are applicable to Tug missions. An analysis of these interface verification objectives revealed that most will be accomplished when the first few Tugs are processed. The primary reason is that most payload-to-Orbiter interfaces are through the Tug and/or deployment adapter, and the Tug-to-Orbiter interfaces become standard in the operational phase. It would be naive, of course, to assume that no interface changes will occur in an eight-year, 165-flight program. In addition, some spacecraft require direct interface with Orbiter (gases and fluid only) that probably would be provided by kit and would require verification on an individual basis.

Two of the objectives require some type of level I integration device:

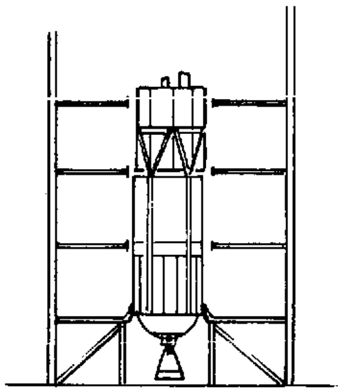
1) Verification that all system interfaces between the payload and Orbiter are functional;

2) Software validation between the LPS, Tug computer, spacecraft computer(s), and the controlling ground station.

The study addressed various techniques for satisfying these two objectives including a fixed level I integration device that would be a replica of the Orbiter physical and functional interfaces, separate and mobile simulation devices, and simulation built into the Tug processing cells. None of these approaches satisfy the software integration objective without an additional simulation laboratory.

Figure III-13 illustrates the recommended approach. Although payload to Orbiter interfaces can be complex, especially on multiple payload missions, many interfaces can be standardized to a large extent through the proper use of a user's guide and analytical integration. If software compatibility and integration is performed in a simulation laboratory, then functional interface verification can be performed during Tug processing in the TPF test cell. Some additional equipment would be required, but one set could be used to service both TPF cells.

This approach would provide a very high level of confidence in interface compatibility before the payload is integrated with the Orbiter.



TPF Test Cell

Tug Project

- Perform Multiple Payload Analytical Integration
- Standardize Interfaces Thru Detailed Tug User's Guide
- Perform Software Compatibility Integration in Upstream Simulation Laboratory Similar to SAIL

Launch Processing

- Build Orbiter Simulation Into TPF Cell
- Perform Orbiter/Payload Function Interface Verification in TPF Cell During In-Line Processing

Additional Equipment

- MSS/PSS Control Consoles
- S/C Unique Panels
- Orbiter Cabling
- Orbiter Payload Support Equipment Simulation
- Cargo Bay Retention Points Built Into Cell

Figure III-13 Recommended Approach - Level I Integration

3.0 Software Integration

Phase I software integration should begin during the programming production phase. This checkout and debugging is accomplished with the computer playing into standard simulation routines. It is highly desirable that the element contractor monitor this software checkout and de-bug; later changes are going to cost more time and money.

Since the phase I simulations are with standard software routines, the simulation may be deficient in nonlinear reactions and certain interactions that will be present later. However, this simulation will check some contingencies and interactions.

Software integration and compatibility verification will be completed in phase II at the end of the verification and validation phase. Figure III-14 illustrates the recommended elements of phase II integration. This phase functions the LPS with the hardware (or its simulators) with the interfacing hardware. The hardware can be a high fidelity mockup, an integration laboratory with both flight equipment and simulators, or with actual hardware.

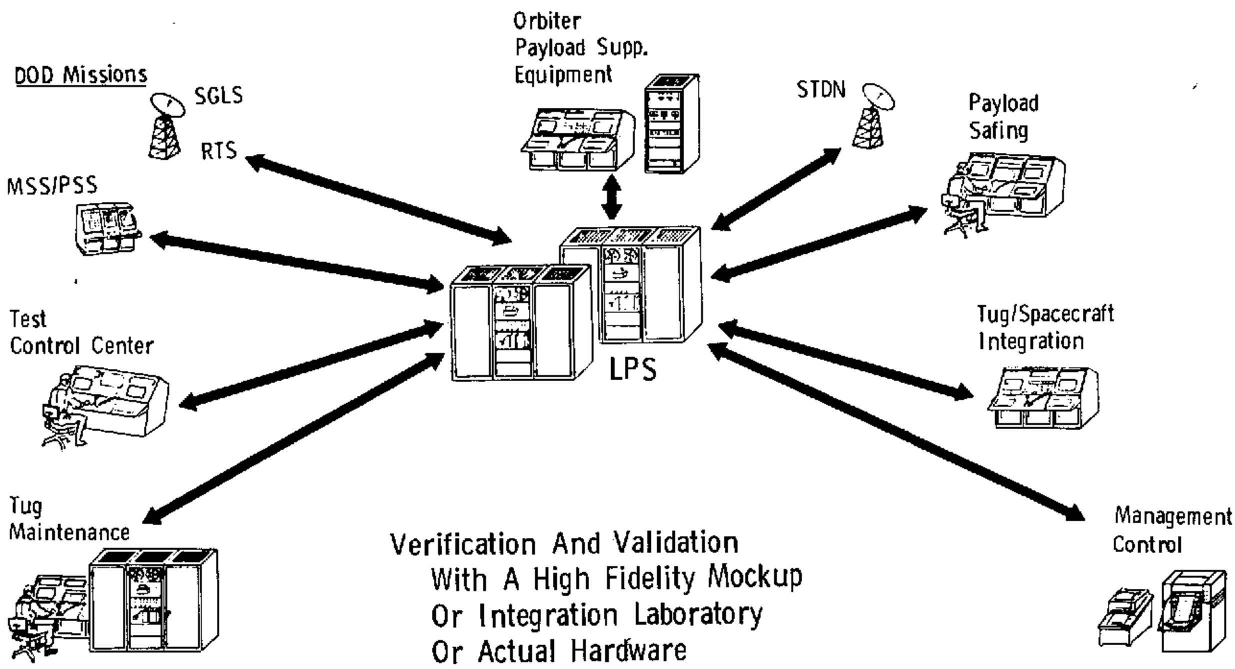


Figure III-14 Recommendations - Software Integration, Phase II

This validation is probably performed at a NASA facility due to the amount of hardware required. The verification and validation is performed with actual interfaces. To increase the validity of the integration, very few sofware simulations should be permitted. Dynamics and interactions should be tested with hardware interfaces.

The criteria for success will be twofold. First, outputs should be compared with the phase I integration (checkout and debug). One-for-one correspondence should be present. Secondly, the dynamics of the equipment are tested against the assigned criteria. After initial usage, this laboratory set up should be maintained for the duration of the program. Each new software program should be played against the laboratory set up to verify compatibility before being shipped to the launch site.

4.0 Tug User Guide

Figure III-15 illustrates a concept proposed in earlier studies--use of a set of handbooks and user guides. Both have received wide acceptance and are being applied. For example, the *Launch Site Accommodations Handbook for Shuttle Payloads* has been published in preliminary form. The *Spacelab User's Guide* is in the review cycle.

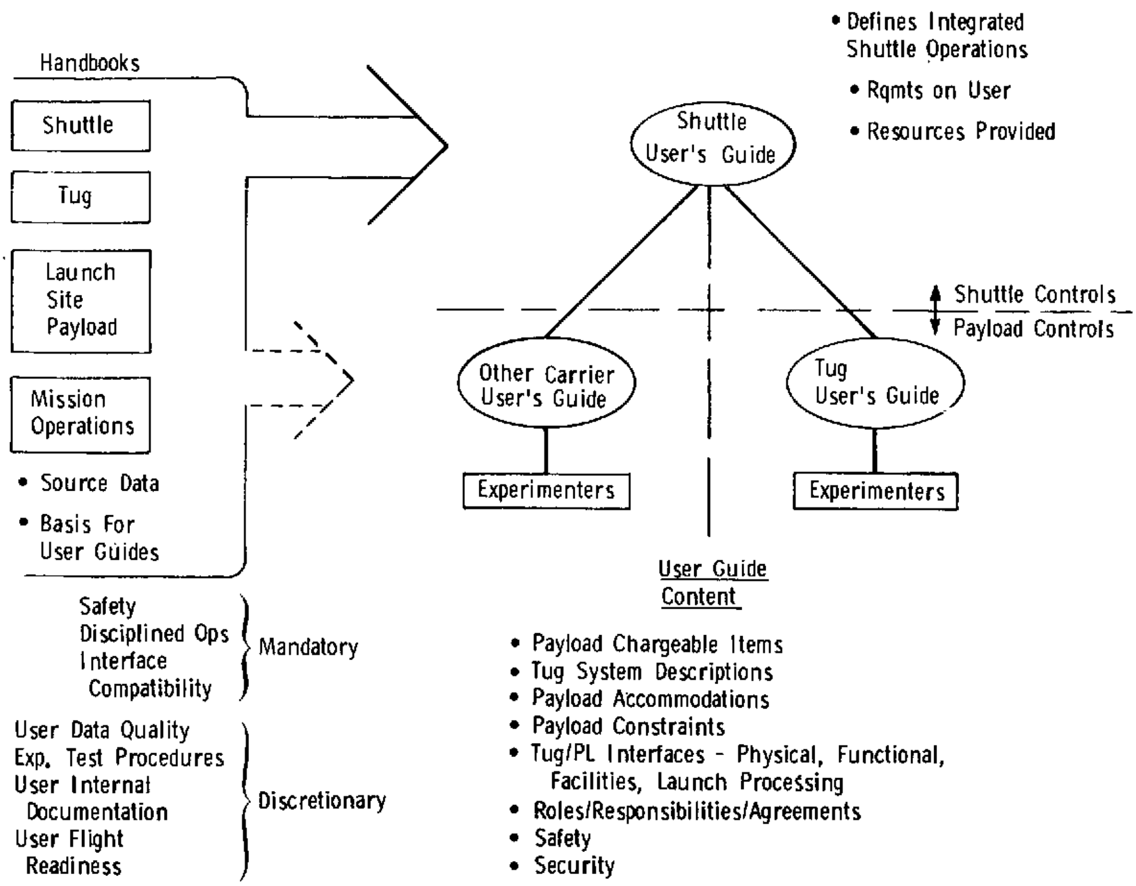


Figure III-15 Tug User Guide

The early development of a Tug user's guide that provides both mandatory compliance data as well as information is recommended. In order to achieve the standardization desired, the user's guide should be published early in the program to provide interface definition to spacecraft development phases.

The final report contains a detailed outline for a Tug user's guide. The user's guide should provide the potential user with information defining what his roles and responsibilities are, as well as what the Tug will provide. Tug system descriptions, payload accommodations, and constraints that the Tug mission will impose on him should be defined in detail. Interfaces with which

he must be compatible--physical, functional, and operational--should be defined. Certain elements of the user's guide are mandatory; others are negotiable.

Mandatory data includes that data to which the user must comply to be compatible with the Tug. For example, certain interfaces will be standard. The user must be compatible with that interface or must provide an adapter. An alternative is for the Tug project to provide an inventory of adapters for Tug users. Safety is another mandatory requirement. All user's must comply with certain safety standards and be able to demonstrate compliance. Generally independent spacecraft operations are discretionary but, when integrated into other elements of the program, such as the Tug or Orbiter, disciplined operations to protect personnel and hardware become mandatory.

Other information is discretionary. For example, assuming that the Tug provides the required accommodations to the user, the quality of data obtained by the user is not the concern of the Tug project. However, years of NASA and industry experience would dictate things that can be done by the user to enhance his data quality. Such information, if included in the user's guide, would be discretionary.

D. SITE ACTIVATION (TASK 5.0), IUS/TUG TRANSITION (TASK 6.0) AND UNCLEAN PROCESSING (TASK 10.0)

The study plan defined three separate tasks addressing site selection/activation, transition, and an alternative factory clean processing assessment. In performing the study, selection of an appropriate facility was driven by the cleanliness level involved in processing, and activation of the facility was effected by the extent of commonality or joint usage possible in the transition period from IUS to Tug. Consequently, these three study elements were performed concurrently with appropriate iterations between the three. It also provides a clearer understanding of results to discuss the three tasks simultaneously.

1.0 Commonality Assessment

In selecting a recommended facility for processing the Tug, one of the decisions that affected the TPF size was whether or not the IUS should be processed in the same Tug facility. To objectively determine the desirability of processing the IUS and Tug together, commonality between IUS and Tug operations was investigated. In the TPF, areas of IUS/Tug commonality are primarily LRU and GSE checkout areas and shop and support areas that are not sensitive or dedicated to the type of hardware processed in that area. Because of the difference in size of the 14.7 ft (4.5 m) diameter Tug and the 10 ft diameter IUS, two different

refurbishment and checkout cell sizes are required in the TPF. It is possible to make cells convertible to either Tug or IUS; however, time to convert and the traffic density indicate that the best approach would be to provide two Tug cells and one IUS cell, if a combined facility is selected. The cryogenic Tug will require a hydrogen burn stack and an external oxygen vent, while the hypergolic IUS will require oxidizer and fuel vapor combustion units. The Tug will use the LPS for checkout and monitoring, requiring an LPS station in the checkout area. Current IUS planning indicates that van-mounted GSE will be used for checkout off-Orbiter and LPS for checkout on-Orbiter. The servicing/pressurization GSE supporting the Tug and IUS MPS will be different. The Tug MPS operating pressure is 17 to 18 psia (11.7×10^4 to 12.4×10^4 N/m^2) while the IUS MPS is a 160-psia (11.03×10^5 N/m^2) system. This GSE would also be procured by two government agencies from their respective contractors. Fuel cell reactants servicing GSE would be peculiar to the Tug, while APS servicing/pressurization GSE could be made common for both stages since the propellant is the same. Because of size differences, the handling GSE will also be different. The LCC would require consoles and racks that are unique to the IUS and unique to the Tug for propellant loading and systems monitoring. Therefore, sufficient area is required in the LCC for both the IUS and Tug propellant loading and system monitor consoles/racks.

There is little commonality of schedules for the IUS and Tug. After IUS IOC in 1980, fairly heavy IUS traffic is scheduled, which will be concurrent with Tug facility construction/modification and activation. After Tug IOC in 1983, the IUS traffic falls off while the Tug performs the bulk of the missions requiring an upper stage.

The IUS ground checkout approach is different from that of the Tug. The IUS approach to minimize costs is to use an existing stage and its support equipment, while the Tug will be designed to use the LPS capabilities. The IUS ground checkout software is keyed to existing van mounted automatic checkout equipment. Some commonality may be possible since the IUS must be LPS compatible in the Orbiter.

There is some commonality in crew skills and training in the area of ground handling and avionics. Cross training might be beneficial in certain skills, but in most systems there is no commonality. For example, with the exception of APS servicing the propellant/propulsion system for the IUS and Tug are different to the extent that cross training would not be practical.

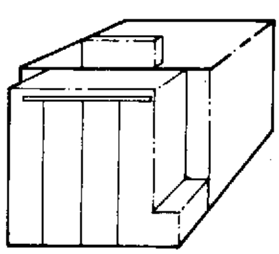
As with training, the areas of commonality with respect to safety requirements fall mostly in avionics, stage handling, and APS servicing. There is very little commonality in the propellant/propulsion systems.

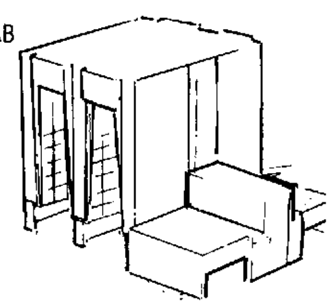
It is concluded that there is little commonality in in-line processing requirements and some commonality in off-line support areas and requirements. Consequently, there is little apparent advantage to a common IUS/Tug facility. The recommendation, therefore, is "do not force fit the IUS into the Tug facility," consider, however, common support shops, storage/warehousing and kick stage processing.

2.0 Unclean Processing Alternatives

Facility selection narrowed down to three candidate locations: SAEF-1, VAB low bay, or a new facility. The third option was viable only if the first two proved to be inadequate. Initial assessments of the SAEF-1 and VAB pointed out that one major discriminator would be the type of environment under which the Tug would be processed.

Figures III-16 and III-17 illustrate this very clearly. In Figure III-16, the two facilities are compared, assuming that the Tug would be processed in a 100K clean environment. The entire processing area of SAEF-1 is a class 100K clean facility. It has an existing airlock, but it would require raising to accommodate vertical processing. This was accomplished once before on SAEF-1 and the cost is not prohibitive. SAEF-1 has fragmentation partitions to make it leak check compatible. The primary disadvantage to SAEF-1 would be the requirement of an additional area for offices and storage.





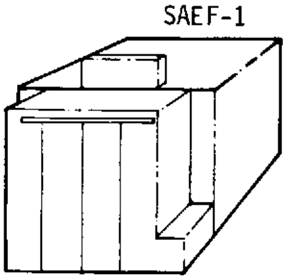
	SAEF-1	VAB
Pro:	Existing Class 100,000 Area Labs and Shops Available Existing Airlock (Mod) Cranes Have Capacity Leak Check Compatible	Sufficient Height for Vertical Processing As Is Can Accommodate IUS and Tug Office, Shop, Lab, and Storage Space Available Cranes Have Capacity
Con:	Airlock Needs Height Increase New Building Required for Offices and Storage	Extensive and Costly Mods to Make 100,000 Clean No Airlock Cells Not Enclosed Cells Not Leak Check Compatible

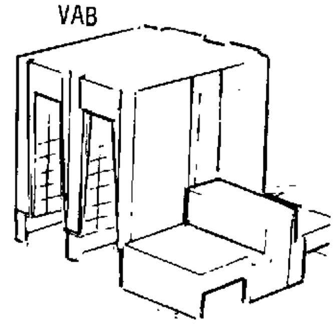
Conclusion: For Class 100,000 Clean Tug Processing, Use SAEF - 1

Figure III-16 Class 100K Clea- TPF Location Comparison

On the other hand, the VAB is a large open bay area with exposed girders. The cost to convert this area to a class 100K clean facility would be prohibitive. An airlock would have to be added, the cells enclosed and frag nets or partitions would be required. Consequently, the SAEF-1 building would be the logical selection for processing the Tug in 100K cleanliness environment.

By contrast, Figure III-17 shows that comparing the same facilities with respect to processing the Tug in a factory clean environment result in the recommendation to use the VAB low bay area. It has all of the same advantages shown in the previous comparison but does not require the extensive and costly clean room modifications or the addition of an airlock. On the other hand, the selection of SAEF-1 would be a poor use of a large class 100K clean area especially when clean areas are at a premium in the Shuttle era.





	SAEF-1	VAB
Pro:	Leak Check Compatible Final Wipe-Down Area Exists Cranes Have Capacity Labs and Shops Available	Sufficient Height for Vertical Processing Work Platforms Available (Mod) Can Accommodate IUS and Tug Office, Shop, Lab, and Storage Space Available Cranes Have Capacity
Con:	Poor Use of 100,000 Clean Area Airlock Mod for Vertical Processing IUS Cannot Be Accommodated Easily New Building Required for Storage, Offices	Cells Not Enclosed Building Not Leak Check Compatible Mod Required to Cell Platforms Mod Required to Provide Clean Room Around Spacecraft When Mated

Conclusion: For Factory Clean Tug Processing, Use VAB Low Bay

Figure III-17 Factory Clean TPF Location Comparison

The feasibility of processing the Tug in a "factory clean" environment was addressed to provide one of the discriminators for facility selection. The Shuttle program imposes cleanliness requirements on the Tug. First, the Tug must be compatible with the Orbiter bay (visibly clean per SN-C-0005); second, the Tug must be compatible with a majority of the spacecraft (class 100K). The correlation between a visibly clean surface and a clean room class is not directly or measurably related. A clean room class measurement is the number of particles of a specific size in a specific volume; visibly clean is absence of particulate and nonparticulate visible to the normal unaided eye. However, based on experiences with the Skylab contamination experiments, the Skylab contamination working group, and subsequent contracted efforts with JSC, the consensus is that by visibly cleaning the Tug surface in accordance with the JSC Specification SN-C-0005, the Tug will be compatible with the prelaunch cleanliness conditions of the Orbiter bay and spacecraft with 100K cleanliness requirements. The basic question then is when and where, during the ground refurbishment process, should the Tug be cleaned? Should it be refurbished in a factory environment in an as-received condition (returned from mission or received from contractor) and then cleaned to the required cleanliness specification just before mating with spacecraft or canister, or should it be cleaned first and then processed in a class 100K clean room and continuously maintained in that environment throughout the prelaunch activities?

The study assessed the impact of the various types of contaminations that might reasonably be expected as a result of the flight environments, processing anomalies, and maintenance cycles. For example, refurbishment due to flight environment degradation or anomalies, such as hydraulic fluid or hydrazine spills, create some significant concerns for processing in a clean room. As an objective, refurbishment should be accomplished before entering a clean room; however, in some facilities, that is not practical. The entire SAEF-1 building, for example, is a clean room with the exception of the airlock area. If that building were selected for TPF, space limitations would dictate that refurbishment be performed in the clean area.

The conclusions of this assessment follow:

1) The Tug is not critically sensitive to contamination with the exception of specific components such as the star tracker which could be protected locally.

2) By designing contamination cleanliness features into the Tug such as cleaning accessiblilty, selection of materials, and imposing flight constraints, no contamination to the spacecraft is envisioned as a result of flying the Tug.

3) Martin Marietta's Viking experience has shown that it will take about 30% longer to refurbish the Tug in a class 100K clean room than in a factory clean area because of the stringent cleaning procedures required for equipment and tools, cleaning materials used, personnel clean room clothing, maintenance requirements, and training programs required.

4) Based on multi-use of the Tug for orbital missions, a sizeable maintenance program with inherent contamination problems accompanying these operations could occur. These contamination conditions could be of severe enough magnitude that operations in a clean room would be costly and time consuming.

The assessment resulted in the following six recommendations with respect to Tug processing:

1) It is recommended that the Tug be refurbished and processed in a factory clean environment.

2) The factory clean facility should be designed for high standards of shop cleanliness such as slick surfaces on floors, walls, and ceilings so that particulate cannot settle on it and then later recirculate because of air currents. Extensive janitorial services should be provided during working periods. Tug sensitive elements, such as the star tracker, should be protected locally.

3) A contamination control plan should be implemented to reduce contamination to a minimum during Tug refurbishment.

4) If a Tug is to be placed in storage after refurbishment, it should be placed in a bag and stored in an environmentally controlled facility to minimize particulate settling on the surface and the chance for corrosion.

5) The Tug should have its surface cleaned just before placing it in the payload canister so as not to degrade the cleanliness environment in the Orbiter payload bay. A spacecraft clean room enclosure should be provided in the factory clean area.

6) For those payloads whose particulate contamination conditions must be controlled to more stringent tolerances than class 100K level, the payload will have to provide the necessary cleanliness protection such as protective shrouds or some local contamination control such as aperture door covers.

3.0 Facility Selection and Activation

Based on the conclusion that there are advantages to processing the Tug in a factory clean environment and supplemented with additional considerations such as cost and operational flexibility

developed in the course of the study, the recommendation is to process the Tug in the VAB low bay. This releases the SAEF-1 for those spacecraft that require 100K clean processing which is attractive from a programmatic point of view.

Figure III-24 presents the recommended flow of hardware through the facilities. Seven options were analyzed after the facility was selected. In the recommended option, both the IUS and Tug are processed in the VAB low bay in a factory clean environment. This implies that classified payloads can be handled in the same facility as commercial and foreign national payloads. As an alternative within the option, all IUS could be processed in the DOD building and all Tugs in the VAB. When DOD requires a Tug, it could be moved to the DOD building after maintenance and checkout. This option would limit classified operations to the DOD facilities.

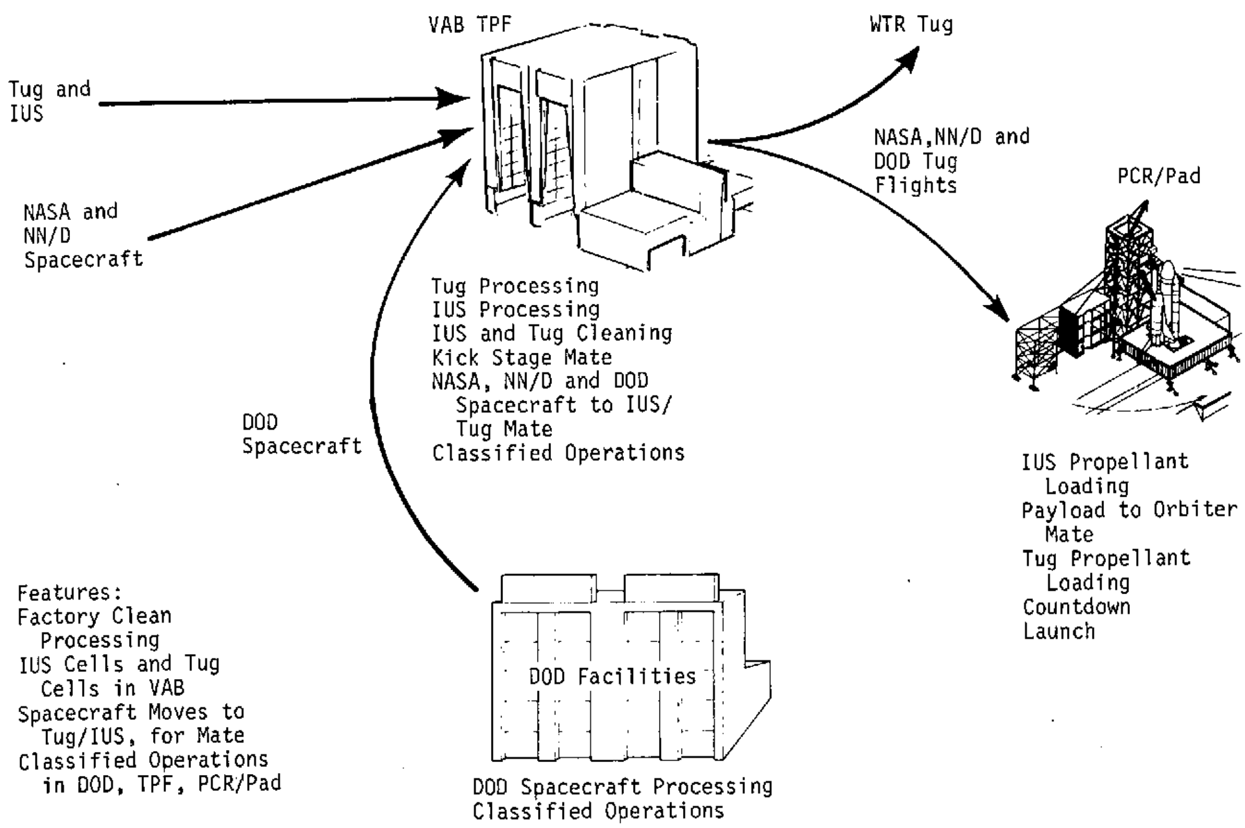


Figure III-18 Option 6 - Factory Clean Processing (Recommended)

Finally, this task addressed site modification and activation requirements. Figure III-25 reflects a milestone schedule for the construction phase. Program requirements must be complete at the beginning of 1980 in order to develop design criteria. Long lead materials must be defined in the fourth quarter of 1980 because some previous off-the-shelf hardware has now gone to two-month lead time and material such as cables have gone out as far as a one-year lead time. There is an incompatibility in the GSE installation date. The present Tug schedules do not show the GSE available for installation until December 1982 while the activation schedule requires it in December of 1981.

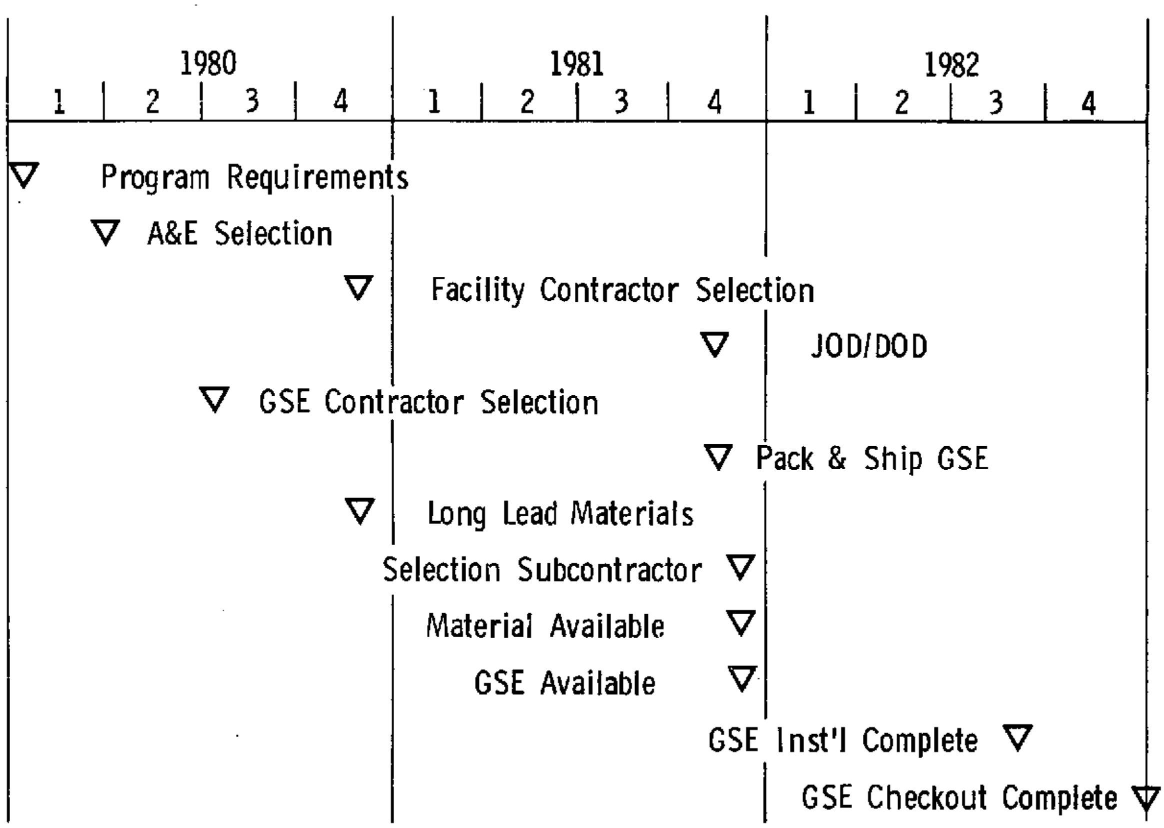


Figure III-19 Construction Phase Milestones

Table III-7 provides a summary of some critical procurement/activation dates. Several significant items are highlighted by the arrows. For example, the pad must be available for modification in February 1981 and for engineering model checkout in April 1983. This is during the peak period of IUS flight activities and will require close coordination between the two programs. In addition, an Orbiter or an Orbiter simulator will be required for approximately three weeks in April 1983 to facilitate Tug propellant loading and countdown demonstrations with the engineering model. The study recommends the use of an engineering model for

site activation (pathfinder approach). This could conceivably be the Structural Test Article (STA) or Propulsion Test Vehicle (PTV) of the Tug qualification program. However, schedule incompatibilities, exist. STA and PTV will not be available until July and November 1983, respectively. The engineering model is required at KSC in February 1983.

Table III-7 Critical Procurement

SITES
SAEF 1 or VAB Available for Modification - December 1980
OPF Available for Modification - April 1981 ←
Pad Available for Modification - February 1981 ←
SAEF 1 or VAB Available for Engineering Model Checkout - February 1983
Pad Available for Engineering Model Checkout - April 1983 ←
EQUIPMENT
Engineering Model at ETR - February 1983
Dummy Spacecraft and Kick Stage at ETR - February 1983
Canister/Transporter Available - April 1983
Orbiter Available on Pad for Engineering Model Checkout - April 1983 ←
Flight Tug on Site - September 1983
Spacecraft and Kick Stage for Mate - November 1983
ASSUME
Go-Ahead - January 1980
First Launch - December 1983

E. IUS/TUG FLEET UTILIZATION (TASK 3.0)

This task performed a fleet utilization assessment from a ground operations point of view. Three main areas were studied: fleet management concepts, contingency analysis, and active/total fleet sizing. To develop a realistic fleet size, it was necessary to perform some sensitivity analyses in this task, although overall sensitivity analysis was performed in Task 9.0 in support of the optimization efforts.

1.0 Fleet Management Concepts

While the study report addresses the elements of fleet management as shown in Figure III-20, only the fleet utilization planning element of management is discussed here. The recommended fleet

management concept uses man and machine in their most effective roles--a mechanized system to provide the data and information, man to make the decisions based on that data.

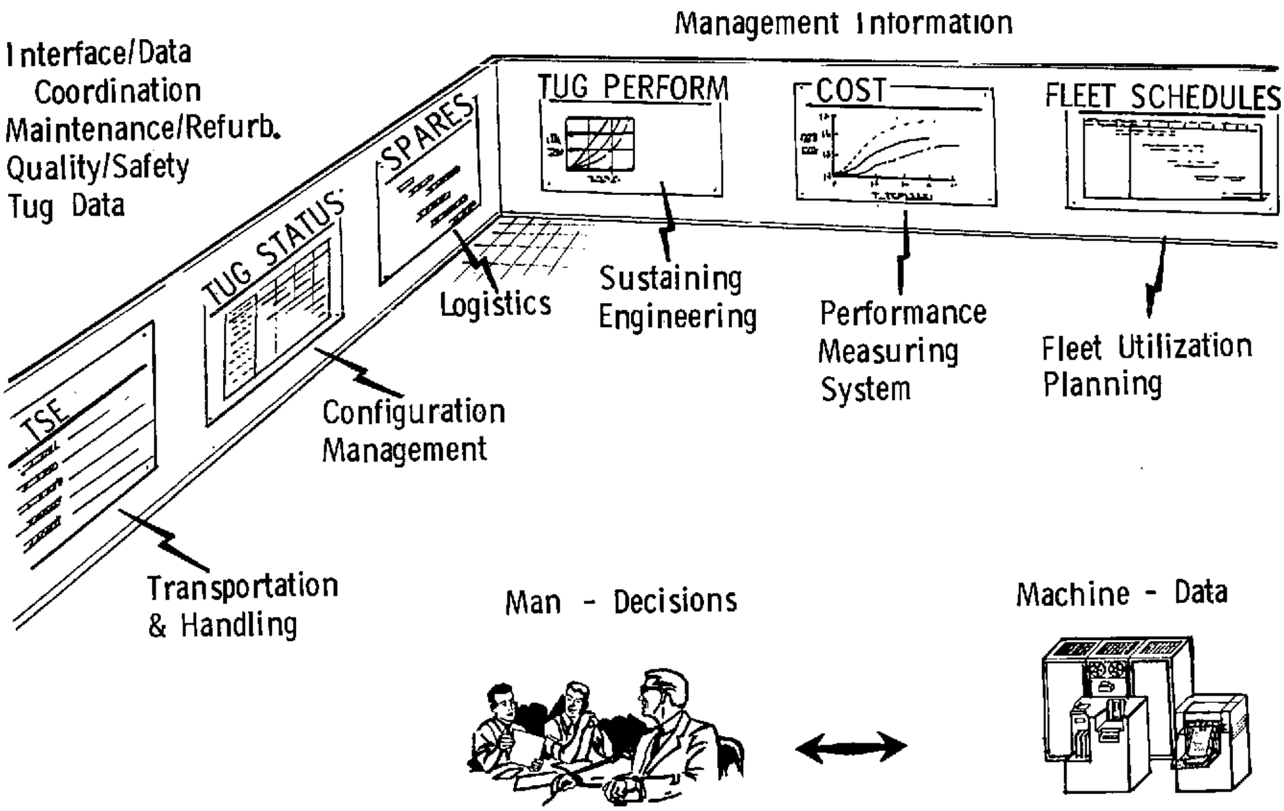


Figure III-20 Fleet Management Elements

The numerous program variables dictate that Tug fleet utilization planning include a mechanized system to assist Tug management. Consider, for example, the problems involved in control and scheduling of 165 flights over an eight-year period, with many of the flights bringing together several spacecraft and kick stages. The Tug fleet annual inventory will vary from two to as high as seven at any point in time. Tugs may have different performance characteristics; flights may occur from ETR or WTR. At any time a Tug could be out of service because of a contingency landing at a remote site. Other contingencies must be accommodated. For example, a given Tug may be randomly out of service for unscheduled depot maintenance at any time.

In addition to hardware and resource variables, Tug fleet utilization planning must be compatible with numerous operational interfaces. Tug utilization planning can be subdivided into Tug payload planning and Tug fleet utilization planning as shown on

Figure III-21. Tug payload planning includes analyzing payload interfaces with the payload agent and developing the Tug traffic model iteratively with the payload agents' mission planning and Tug flight planning. For payload planning, mechanized systems exist, and more comprehensive systems are being developed to assist in the planning. Tug fleet utilization should be iteratively planned with the three areas and with Tug ground operations planning, Tug orbital operations control planning, and the spares status and inventory to develop the project level utilization plan. This plan must be integrated with the STS/Shuttle plan. The heavy payload traffic and long Tug operations program that is planned, the large number of parameters that must be considered for each mission's priorities, and the necessity for both rapid contingency and recovery planning establish the requirement for mechanized planning assistance. Because of the complex nature of the fleet utilization planning task, man must be kept in the loop to make the basic decisions.

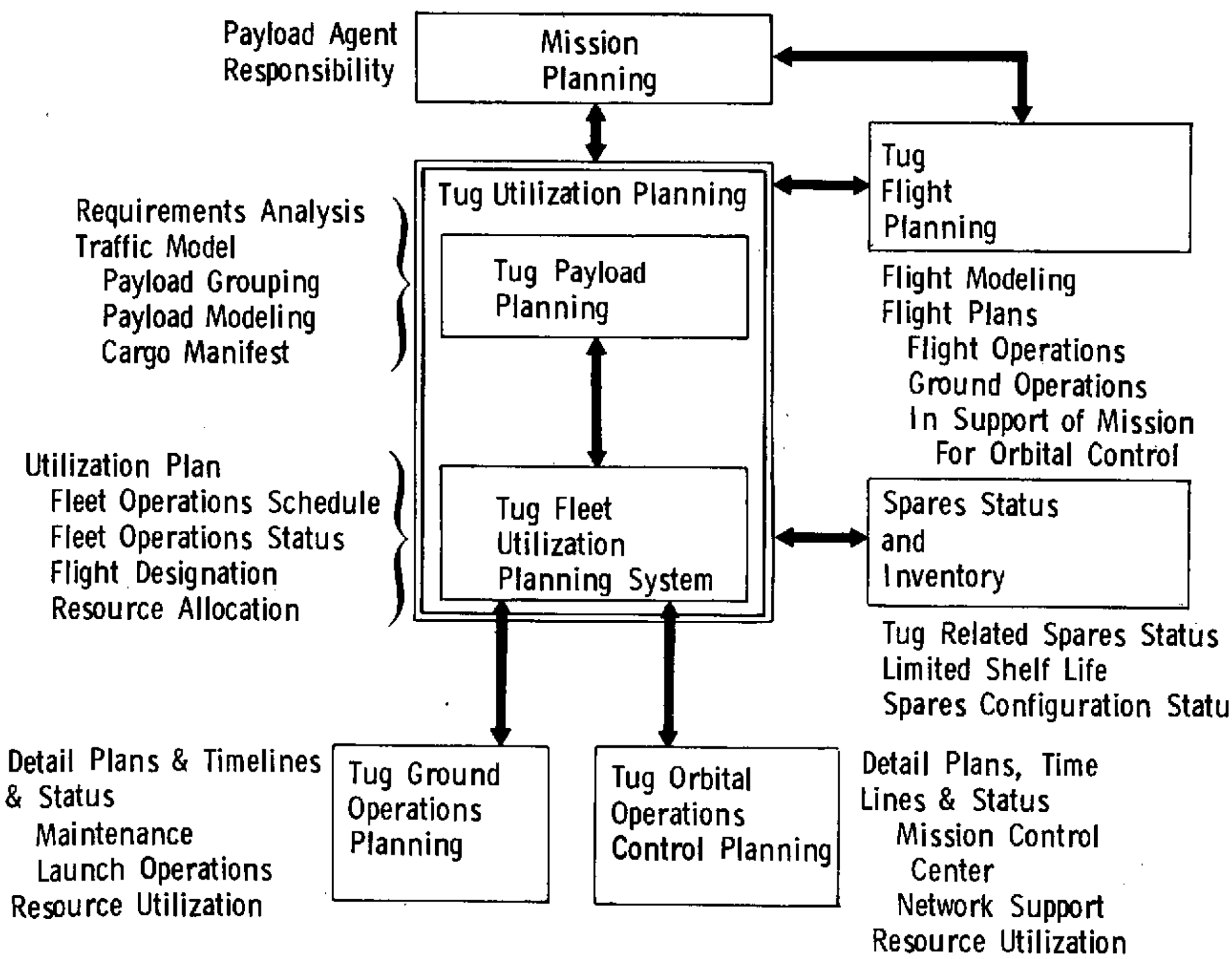


Figure III-21 Tug Utilization Planning

The system must be capable of providing tenative utilization plans or planning aids, must readily accommodate the input of changes, and must produce firm utilization plans and associated status data for different planning horizons and corresponding levels of detail in the format required for project implementation. This can be achieved by providing two computerized segments and two levels of data set inputs.

The necessary intervention of man is essential if the Tug fleet utilization planning system is to have the adaptability to accommodate the continually changing planning requirements. The method recommended, as shown in Figure III-22, provides the two computerized elements of this system with the capability to readily accommodate changes in Tug operations requirements and planning levels by input data set changes rather than algorithm changes. This is facilitated by dividing the manual input data into a problem dependent data set and a data base. The data base inputs the normal (green light or current utilization plan) logic into both computerized elements. The problem data set will normally be changed for each tentative planning cycle. Trend analysis changes are input manually through the data set affected. By using the manual input data approach described above, changes to operational networks, system resources, and planning horizons are readily accomplished and do not require algorithm changes.

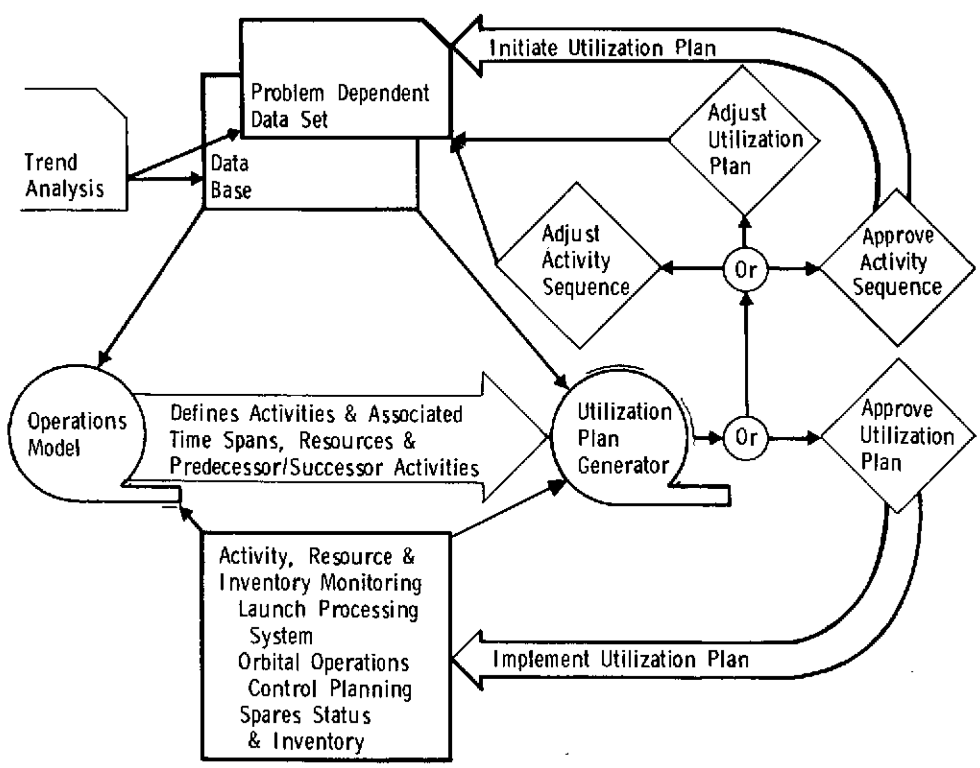


Figure III-22 Tug Fleet Utilization Planning System

The operations model maintains an intermediate (project) level description of Tug ground and flight operations. This description is designed so that more summary description levels may be selected by man. Included are the activities that might be required for a particular Tug flight, the resources available (Tugs, ground support equipment), and the temporal relationships between activities (payload unloading must be finished before payload checkout begins). Each activity has, as part of its description, its duration and the resources required to complete the activity. The description of the available resources may include quantity, characteristics, and assignments made for each resource. (Certain payloads must be assigned to a pool of Tugs with specific modifications incorporated.) The temporal relationships between activities may include simple predecessors or more general relationships, depending on the structure of the Tug operations.

The operations model must extract appropriate activity and resource data from more detailed data bases, like the data base for the Launch Processing System (LPS), and be readily compatible with the less detailed operations descriptions used by the utilization plan generator. When a particular set of flights is to be scheduled, the necessary information is extracted from the operations model and provided to the utilization plan generator. Thus, changes to Tug operations that result from trend analysis must be reflected in the operations model. The primary feature of the operations model is that changes in the operations description are made as changes to the data base input, rather than as algorithm changes.

The utilization plan generator must be able to accommodate large operations consisting of many activities and resources, and be capable of producing tentative schedules quickly to support man-machine iterative planning. This indicates the use of classical project scheduling techniques. Classical project scheduling uses a relatively simple model requiring inputs of activity durations and preceding/succeeding activity constraints, quantities of resources needed by the activity, and available resource levels. Complicated resource characteristics (the requirement to specify the level of maintenance a Tug achieves after each activity) and temporal characteristics (the requirement to accomplish two launches within a maximum instead of specified or minimum time) are purposely eliminated. The program can then provide good tentative schedules with men resolving the conflicts that are difficult to express numerically.

Classical project scheduling will perform critical path analysis. Resource level constraints are recognized, and temporal and resource related conflicts are detected and identified in the output. Contingency resource level considerations and resource smoothing capabilities are provided.

The utilization plan generator has a requirement similar to that of the operations model for extracting status data from more detailed data bases, like the LPS for Tug ground operations, and using it to obtain the less detailed data that is required for utilization planning. The data are used to status existing utilization plans and to show actuals for completed activities on new plans.

The method selected for fleet utilization planning must have adaptability to accommodate the continually changing planning requirements. Part of the flexibility is provided by the convenient intervention of man. The method must accommodate changes to operational networks and revisions to resources available. In addition, the system must accommodate varied planning horizons and levels of detail. For example, Table III-8 shows some typical planning horizons for the Tug. Each of these would probably require a separate planning module. An eight-year schedule was selected because it gives visibility over the duration of the projected traffic model.

Table III-8 Typical Schedule Horizons

Horizon	Cycle Time Basis for Horizon	Level of Depth
8 years Soft	Duration of Projected Traffic Model	Top Level Planning
3 years Intermediate	Nominal Payload Development Time	Payload Schedules and Milestones
1 year Firm	Cargo Manifest Cycle	Required Accommodations
6 months Firm	Nominal Integration Time at Development Center	More Detailed Facilities/ Resources
6 weeks Firm	Nominal Spacecraft Checkout Time at Launch Site	Operations and Handling at Launch Site
157 hours Firm	Nominal Tug Turnaround Time	Detailed Checkout, Maintenance and Integration

A three-year intermediate schedule was selected because it provides visibility across the period of time nominally required for spacecraft development; and the capability to detect early problems developing in spacecraft schedules. Four firm schedules were selected ranging from the one-year cargo manifest cycle to the 157-hour turnaround cycle for the Tug.

While planning should become more detailed as utilization approaches, planning needs can be roughly grouped in the following categories:

1) *Firm Plans*: Should cover approximately the next year with adequate detail for recovery planning at any time. This results in maximum detail for the next launch.

2) *Intermediate Plans*: Should normally cover approximately two years beyond firm plans to provide adequate time for long lead item identification. For some missions the period may be much longer. Less detail is required than for firm plans, but sufficient detail for recovery planning should be maintained.

3) *Soft Plans*: Needed for projected duration of the program beyond the intermediate plans. Only the minimum detail required to define Tug ground and flight operations support for the longer range payload and flight modeling should be maintained.

2.0 Contingency Analysis

Contingency analysis must be implemented in the planning stage of the Tug program, and continue to effect real-time solutions involving rescheduling when a contingency occurs. The proposed real-time contingency analysis techniques use the man/machine relationships described in the Tug fleet utilization planning.

In the proposed method for handling real-time contingencies, man and machine work together. The computer presents alternatives; the man selects the alternatives. The computer simulates the effect of the alternatives on both the Tug and other STS elements; man chooses the most desirable approach. The machine then helps man to implement the change. For this approach to be effective, advanced payload utilization planning must identify and provide for certain capability in the system.

Figure III-23 identifies the advanced planning methodology used to identify contingencies, select system provisioning to accommodate these contingencies, and identify resources needed today to become part of the system baseline for long lead planning. These steps follow:

1) Identify Potential Contingency Situations - Includes failures (no-go) in every Tug system element such as Tug, GSE, kick stage, facility and every system element that interfaces with the Tug such as spacecraft, PCR, LPS, canister and Orbiter. It includes schedule problems (no-shows) for most of these elements, and considers programmatic changes such as major program schedule changes, priority payload, or uneven launch centers.

2) Assess Each Contingency Across Each Tug Ground Processing Phase and Identify Alternatives for Each Phase - This resulted in a matrix of potential solutions (alternatives) for each contingency, depending on when the contingency occurs in the flow. Alternatives will vary widely with point of time. For example, the alternatives available for a spacecraft failure at T-2 hours are considerably narrowed from the alternatives available if the spacecraft fails six months before launch.

3) Identify Selective Contingency Provisions - Analysis of the maxtrix resulted in identifying provisions in the system/ program, which should be incorporated early into the overall design to allow accommodation of real-time contingencies. The process is selective, based on a preponderance of contingencies that may be accommodated by a single provision.

4) Identify Contingency Planning Resources - Planning resources are those contingencies that must be defined early in the system in order to implement the timely workaround of real-time contingencies later.

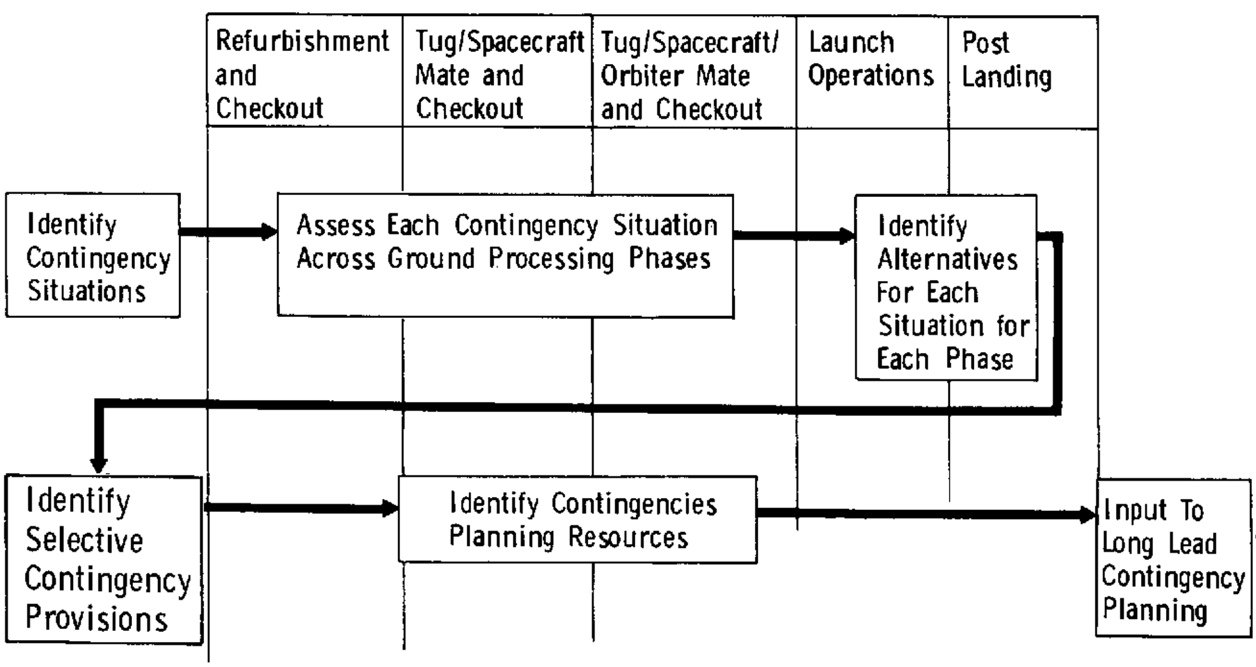


Figure III-23 Contingency Analysis Methodology

The various alternatives that are possible in case of any system element no-go are presented in simplified logic form in Figure III-24. It represents the entire range of choices with alternatives for various no-gos. The bullets under the "Fly Alternate" block are alternatives for system element no-gos that result in not being able to fly the original spacecraft, Tug, kick stage on schedule.

The diagram serves as a road map for contingency planning initially, and summarizes the results of the planning. In a similar manner, system no-shows and programmatic contingencies have been assessed. No shows include such things as a late delivery of the spacecraft or failure of an element to qualify for flight. Programmatics include such things as a shortage of commodities.

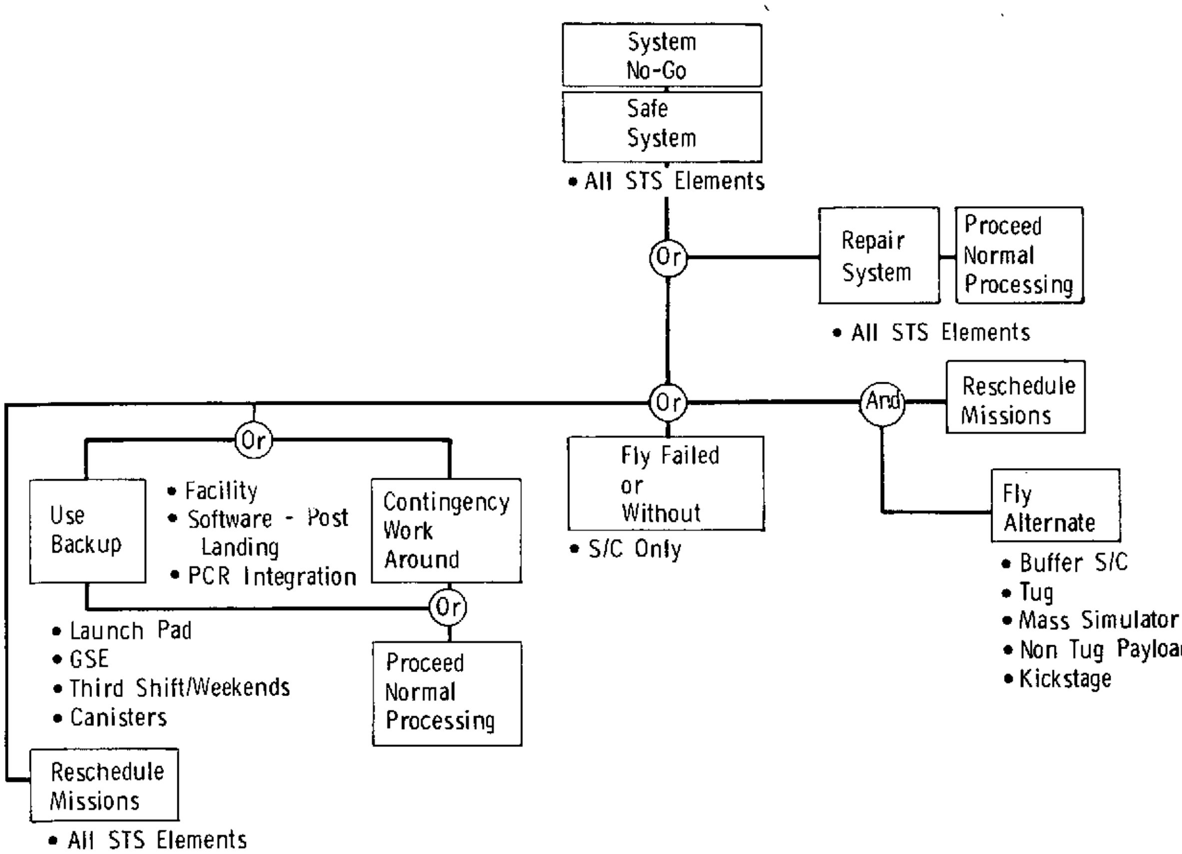


Figure III-24 Identify Contingencies - System No-Go

Figure III-25 identifies some of the contingency planning provisions which, if implemented on an advanced planning basis, will provide viable alternatives to solve no-go and no-show contingencies that could occur in real time. Such provisions could prevent major schedule perturbations and allow the program schedule to be maintained.

Airborne Hardware Provisions

- Backup Tug
- Backup Kickstages
- Buffer Spacecraft
- Mass Simulator - S/C

GSE Provisions

- Functional Redundancy in Design (No Critical SFP's)
- Add Additional End Items 5 Only - Those>30% Usage
- Remote Site Safing & Handling

Facility Provisions

- Storage for Backup Tug & Kickstages
- Additional Test Cell in TPF
- Functional Redundancy in Design (No Critical SFP's): Propellant Loading, Pressurization, Power, LPS, Canisters, Launch Pad
- On Pad-Tug/S/C Mate and Integration
- OPF Installation of Tug
- Remote Site Safing
- Payload Changeout Compatibility at Pad

Other Provisions

- Increase Work Day/Week. No Additional Crew for ETR
- Increase Crew 25% for WTR
- Schedule and Control System
  - Assess Schedule Impacts
  - Define Alternatives
  - Aid Man-Made Decisions

Figure III-25 Contingency Provisions Summary

Not all of these are easily provided. For example, the payload buffer has frequently been proposed as a means for providing flexibility. Feasibility of the buffer concept depends on several variables such as time until launch for substitute, excess payloads available, integration complexity, and compatible launch windows. However, Tug and Shuttle characteristics, such as standard interfaces, families of standard adapters, benign environments, few payload-to-payload interactions, and adaptable flight plans, make the concept at least worthy of consideration.

In terms of facility provisions, we recommend that certain options be provided. For example, although we recommend payload installations on the pad, horizontal installation in the OPF should remain an option as an alternative.

With adequate flexibility built into the facilities, GSE, and mechanized fleet utilization system, real-time contingencies can be handled efficiently. Figures III-26 and III-27 illustrate the operation of the fleet utilization planning system in real time.

When the utilization plan status report identifies spacecraft CN-51A as being two weeks late, the Tug fleet utilization plan computer is queried by manual input for the generic list of alternatives under the category of late spacecraft. A specific list of alternatives is then manually prepared and reviewed for feasibility and completeness.

Modifications are made to the manually input data base, if required, and to the problem-dependent data set for each variation of the feasible alternatives to be assessed. The input data are also revised to limit the output of the utilization plan generator to the minimum satisfactory detail level and to only the time-phased portion of the utilization plan that is affected.

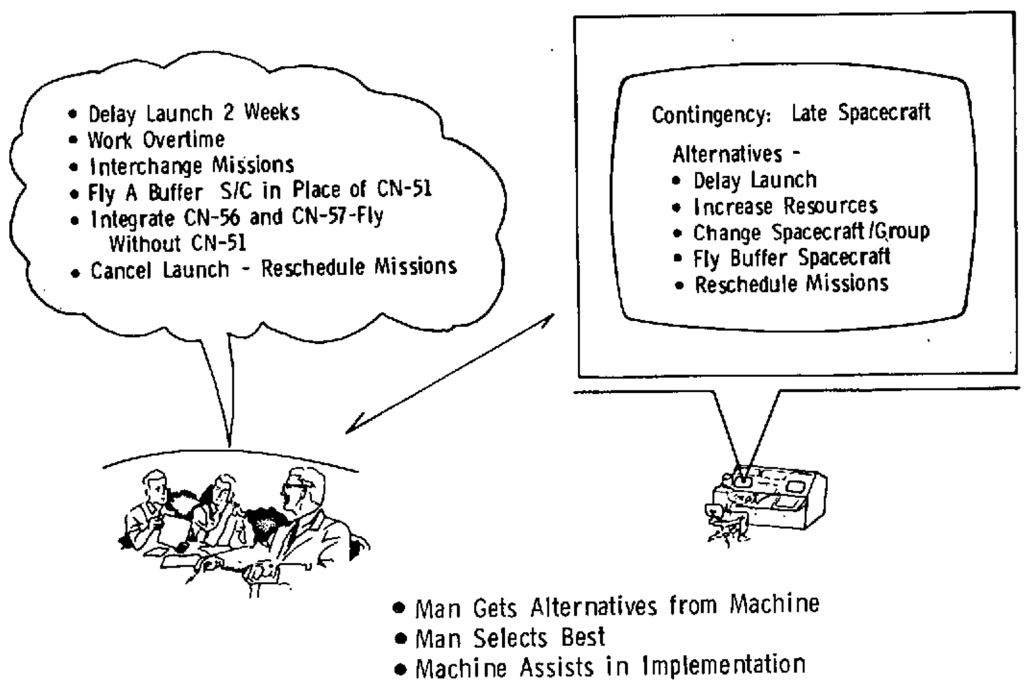


Figure III-26 Contingency Management - Determine Alternatives

The output data from the utilization plan generator can include activity sequence so the program logic can be checked; planning aids such as critical path analysis, the effect of additional resources, and resource smoothing; diagnostic data identifying temporal- and resource-related conflicts; and tentative utilization plans. During the preparation of these tentative plans, the data are iterated with the other planning areas, including STS/Shuttle planning, as required for the detail being considered. These data are reviewed, and the plan to be implemented is defined.

Data are manually input for final changes to the utilization plan and to provide for the normal level of detail in the firm utilization plan. Iteration with other planning areas is then extended to this increased detail level and the resulting approved plan is implemented as a revision to the existing utilization plan.

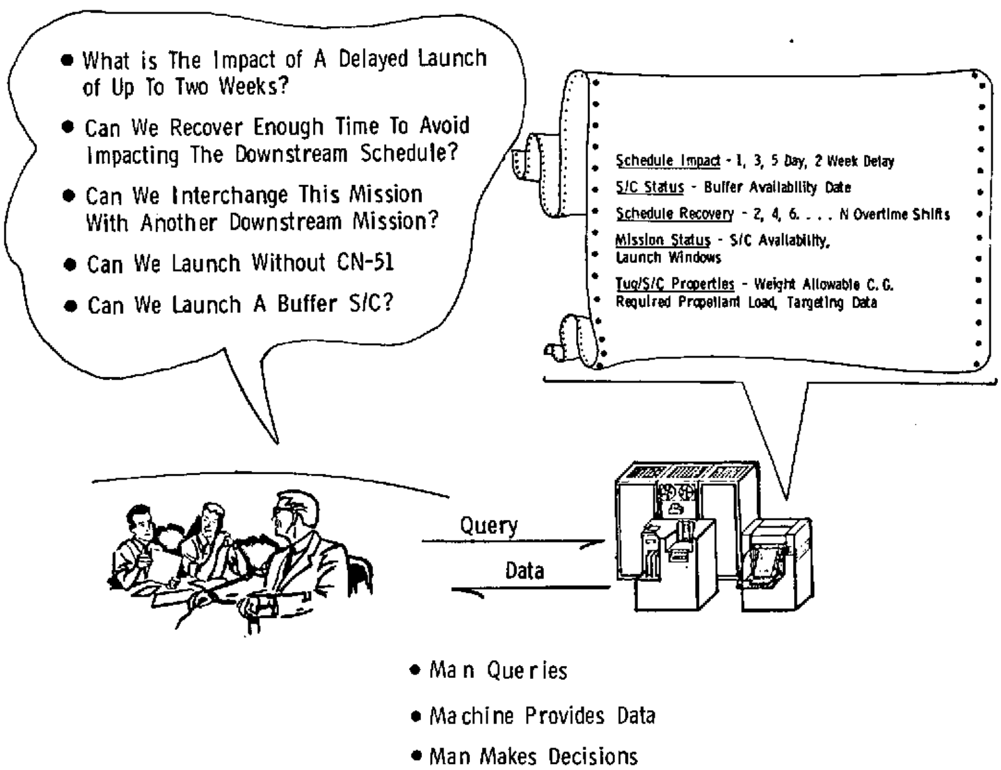


Figure III-27 Contingency Management - Assess Alternatives

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3.0 Fleet Sizing Analysis

Using the current traffic model of the 165 Tug flights (includes 8 expendable flights), and using optimized scheduling, Figure III-28, shows the number of Tugs required. The total Tug requirements are shown to be 14 for the program duration. This is based on three things: expendable flights, maximum number of flights per Tug, and reliability losses estimated at one loss/100 flights.

	1984				1985				1986				1987				1988				1989				1990				1991				Flights/ Tug
Tug No 1	1	1	2	1	2																												7
Tug No 2	1	2	1	1	2																												7
Tug No 3	1	1	1	2	2																												7
Tug No 4	1	1	1	1	2																												6
Tug No 5					1	2	2	2	3																								10
Tug No 6					2	2	2	1	3																								10
Tug No 7										1	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1								19(20)
Tug No 8										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				20
Tug No 9										1	1	1	1	1				1		1	1		1		2	1	1	1	1	1	2	2	20(18)
Tug No 10										1	1	1	1		1				1			1		1		2	1	1	1	2	2	2	19(20)
Tug No 11										1	1	1	1		1			1	1	1		1	1		2	1	2	1	1	1	1	1	20
Tug No 12										1	1	1	1				1	1	1	1	1			1	1	2	2	1	1	1	1	1	20
Total Flights	19				22				24				18				18				16				26				22				165

Tug No 13 }
Tug No 14 } Lost

Total Tugs = 14

Tug Requirements Are Not Dependent on Build Rate So Long As Active Fleet Size Requirements are Met

Figure III-28 Tug Requirements - Early Build and Delivery

The figure shows an example of a schedule whereby all of the Tugs are built, delivered, and are operational within the first 2½ years of the operational program. Similarly, the schedule could be revised to show a slow build, delivery, and use (outlined in the schedule by the zip tone area), to satisfy a "block" design concept without affecting the number of Tugs required simply by flying each Tug more often after 1984, 1985 and the first quarter of 1986. The number of Tugs required will be the same in either case because of the large number of expendable flights in 1985/1986--6 of the 8 total.

If the traffic model schedule and sequence changes, the total number of Tugs required could change even though 165 flights are made. The basic formula for determining the number of Tugs the program requires is presented in Figure III-29. It is segmented into three categories: total number of expendable flights (may be thought of as expendable Tugs); total number of flights by Tugs not expended (to obtain total number of nonexpended Tugs required); and Tugs lost because of unreliability. This gives an idea of the relative importance of the expendables to the total fleet size merely by examining the formula. If the expendable flights can go down and/or the number of flights per expendable Tug can go up, the fleet size can be optimized.

$$\text{Total Tugs Required} = \text{Total Number of Expendable Flights} + \left[\frac{\text{Total Number of All Tug Flights} - \text{Total Number of Flights By Tugs Being Expended}}{\text{Maximum Number of Flights per Tug}}\right] + \text{Unreliability Losses}$$

$$= 8 + \left[\frac{165 - (\text{Varies From 56 to 105})}{\text{Baseline of 20}}\right] + \text{1 Per 100 Flights (2 Total)}$$

$$= 8 + 3 + 2 \text{ To } \underset{\text{Baseline}}{8 + 6 + 2}$$

$$\boxed{\text{Total Tugs Required} = \text{13 To 16 Depending on Expendable Flight Schedule}}$$

Figure III-29 Total Number of Tugs Required - Entire Program

Figure III-30 illustrates that sensitivity. The number of Tugs required is a function of the number of expendable flights in the traffic model. The sensitivity of the number is related also to the number of flights each of those expended Tugs can make before they are expended. The current traffic model dictates the probable zone to be between 7 and 14 counting the expended flight; therefore, the number of Tugs required could vary between 13 and 16 (with 8 expendable flights). From point of view of Tug requirement, two things are required: (1) work the traffic model to maximize the number of flights the expendable Tugs may make before being expended, and (2) try to reduce the number of expendable flights required.

To further emphasize sensitivity, if we ignore the shaded probability zone and use the 8 Tugs that are to be expended on first flight, the total fleet requirements would increase to 18. At the other extreme, if we were able to manipulate the traffic model so that each Tug had 19 flights before being expended on the 20th flight, our total fleet could be reduced to 11.

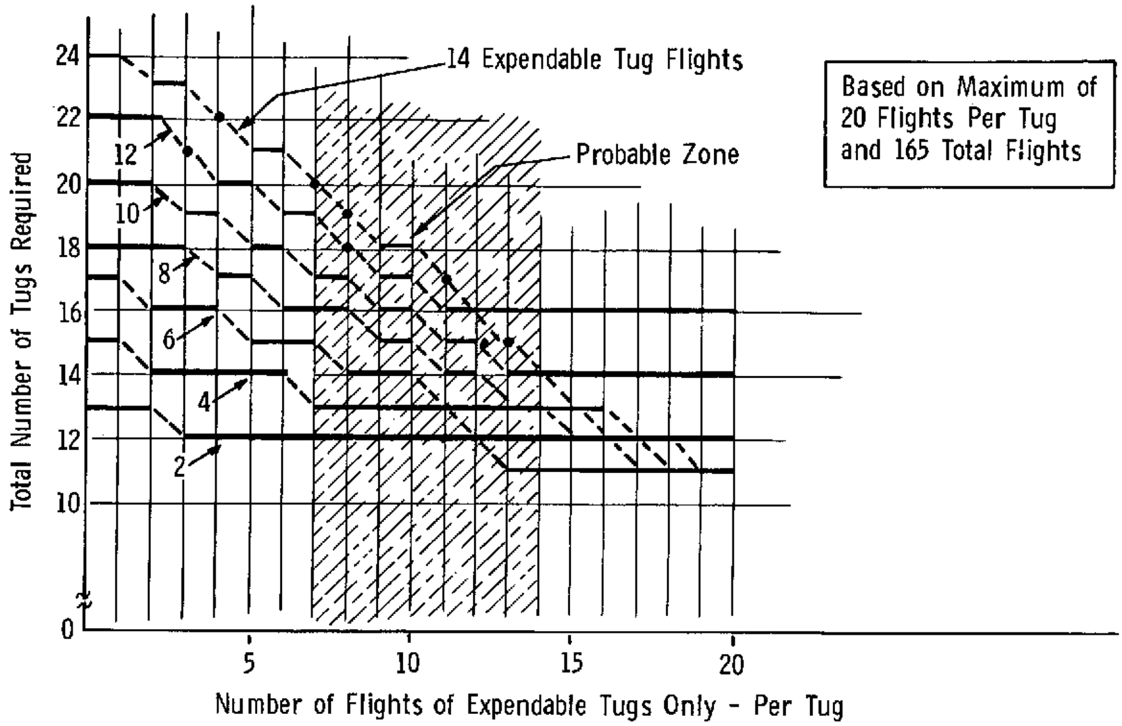

Figure III-30
Sensitivity to Number of Expendable Flights and Flights/ Expendable Tug

The active fleet size required is a function of Tug ground turnaround time, annual launch rate, and working days between launch centers. The curve on Figure III-31 shows the fleet size sensitivity to each of these parameters. The curve indicates a probable need for two active Tugs and one backup Tug. The probable zone indicated on the curve is based on:

1) Task 1 turnaround time of approximately 160 hours;

2) the Tug maximum launch rate from the traffic model;

3) launch pad refurbish of five days between launches (two launch pads - dictates minimum launch centers of five days).

The active fleet size curve does not yield the annual Tug inventory requirements. Two other factors need to be included: the expendable Tug launch rate and the number of flights each expendable Tug makes.

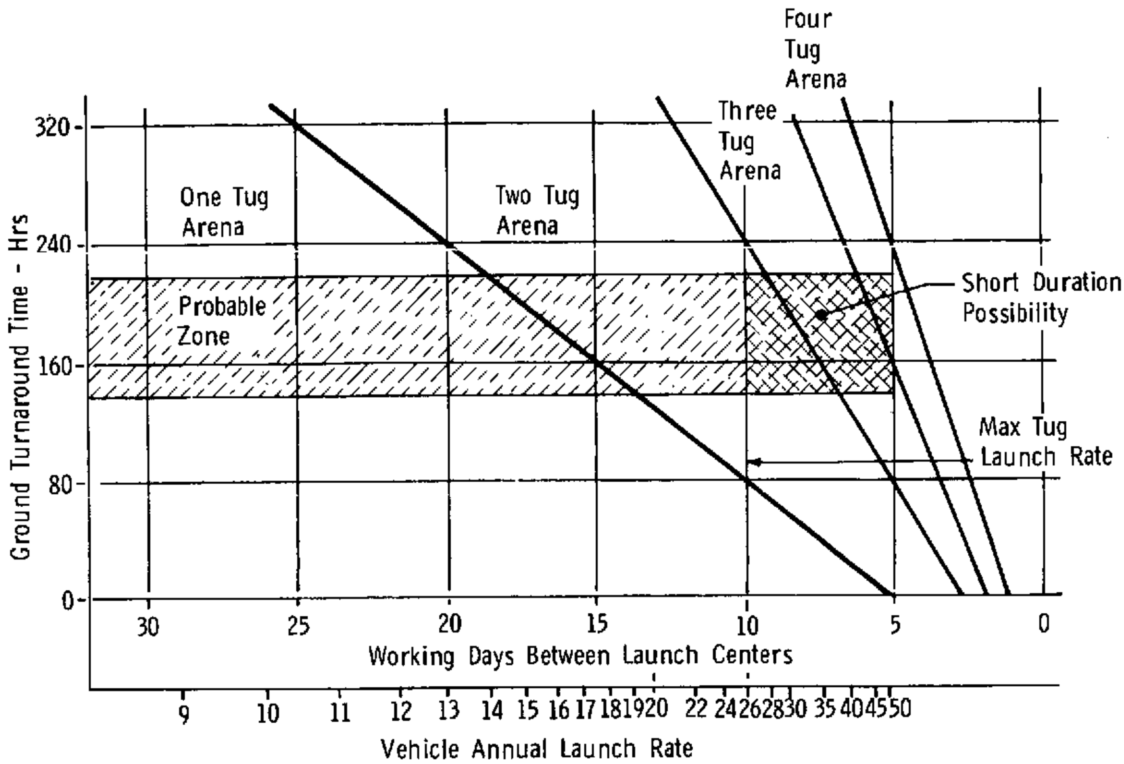

Figure III-31 Vehicle Active Fleet Size

The minimum annual Tug inventory requirements are shown on Figure III-32. The current traffic model includes four expendable flights in 1985 and two in 1986. To satisfy the launch rate, the expendable rate, and to minimize the total fleet size, the annual Tug inventory requirements in 1984, 1985, and 1986 are high. In 1987, 1988, and 1989, the active fleet size is a function of turnaround time, a launch rate, and launch centers only, as there are no expendable flights in those years. The inventory requirements in 1990 and 1991 are up, again because of one each expendable flight in those two years.

It is noted that no backup Tug is needed in 1984 because of the availability of the expendable Tugs during that year. For the years 1985 on, a backup should be added to the quantities shown in the illustration for contingencies. If in 1985, 1986, 1990, 1991, any or all of the expendable flights occur in the last quarter of that year, probably no backup would be needed for that year. In any case, the backup Tugs do not affect the total fleet size.

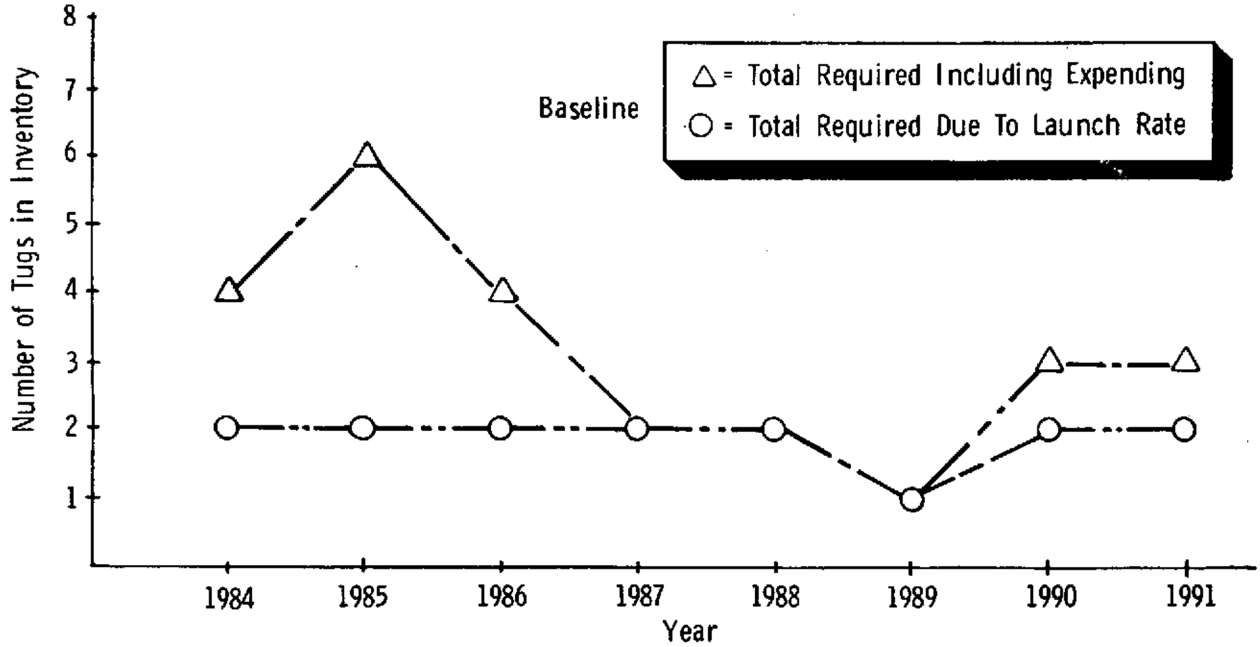

Figure III-32 Minimum Annual Tug Inventory Requirements

The Tug fleet size requirements can be summarized as follows:

1) The current traffic model requires 14 Tugs.

2) The baseline requirement could vary between 13 and 16 total Tugs.

3) Total Tug requirements are sensitive to

- total number of Tug flights,

- total number of expendable flights,

- total number of flights each expendable Tug can make before being expended.

F. COST ESTIMATIONS

At the conclusion of the study, cost estimations were performed to develop ground operations costs per flight. Mission operations costs are being developed under another NASA contracted study. Cost estimates from that study must be integrated with these costs to obtain total operations cost. Our approach to the cost estimate is shown in Figure III-33.

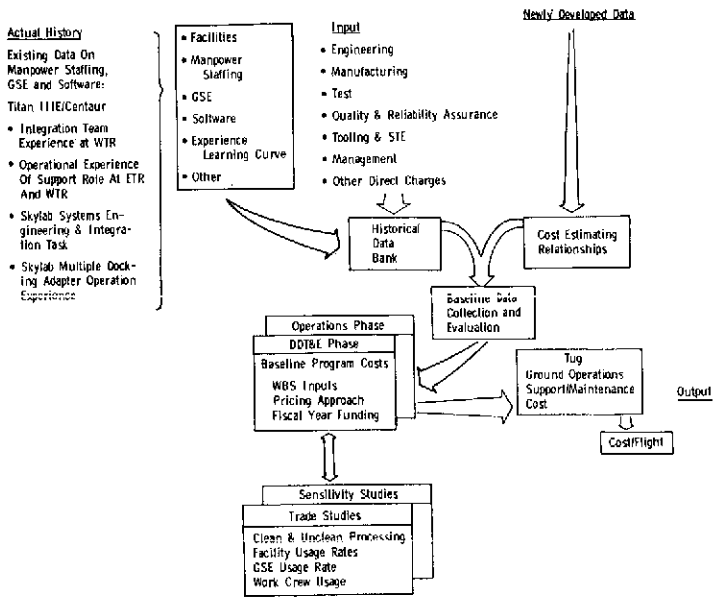

Figure III-33
Tug Ground Operations Life Cycle Cost Approach

A detailed bottoms-up approach was used in estimating each task. Appropriate engineering personnel created manpower requirements at WBS levels 5 and 6. Material, GSE, and facility modifications were estimated using engineering estimates of the materials and manpower required. The costs of some items were based on recent modification costs at KSC for similar items. Ground operations costs for the operations phase were based on crew sizes related to requirements as experienced in our Titan, Viking, and Skylab programs. The detailed inputs were then evaluated parametrically using historical factors and cost estimating relationships.

The total program costs were based on providing the cost of a contractor-operated program for the DDT&E phase 1980 through 1983 and operations phase 1984 through 1991.

All material costs and labor rates are based on fiscal year 1974 dollars. No rate escalation or inflation factors were added. Pricing ground rules included:

1) Construction costs for the central processing facility were limited to ETR building costs. No facilities were built at WTR; however, modifications to the PRR/pad for minimum launch capability were included.

2) WTR launch and recovery are performed by a 41-man crew, 34 flown in from ETR. This crew performs the prelaunch checkout of the vehicle, stays at WTR during the mission, and safes the vehicle when it returns to WTR before its ferry flight to ETR.

3) Processing Option 6 (factory clean processing in the VAB) was used to show the minimum cost approach to handling the Tug. This type of controlled factory environment reduces facility maintenance costs.

4) Crew sizing at ETR was designed to support Tug processing with a two-shift operation and a Tug turnaround time of 160 hours. Additional personnel were added to continue this operation while supporting WTR launches.

5) Fleet utilization project management was staffed to handle the overall task of scheduling Tug fleet operations, providing sustaining engineering effort, cost/performance management, inventory control, and Tug project management.

The Work Breakdown Structure (WBS) provided the framework for structuring the various management and technical plans, operational schedules, cost and manpower estimates for the DDT&E and operations phases. The Fleet Utilization Project Management 320-1A contains the subelements necessary to overall program management. Ground and launch operations at ETR and WTR are identical in types of subelements, but differences occur in lower level items because of the nature of the program and the particular site functions. Figure III-34, a brief summary of the WBS used, shows levels 3 and 4. Cost estimates were generally made at levels 5 and 6.

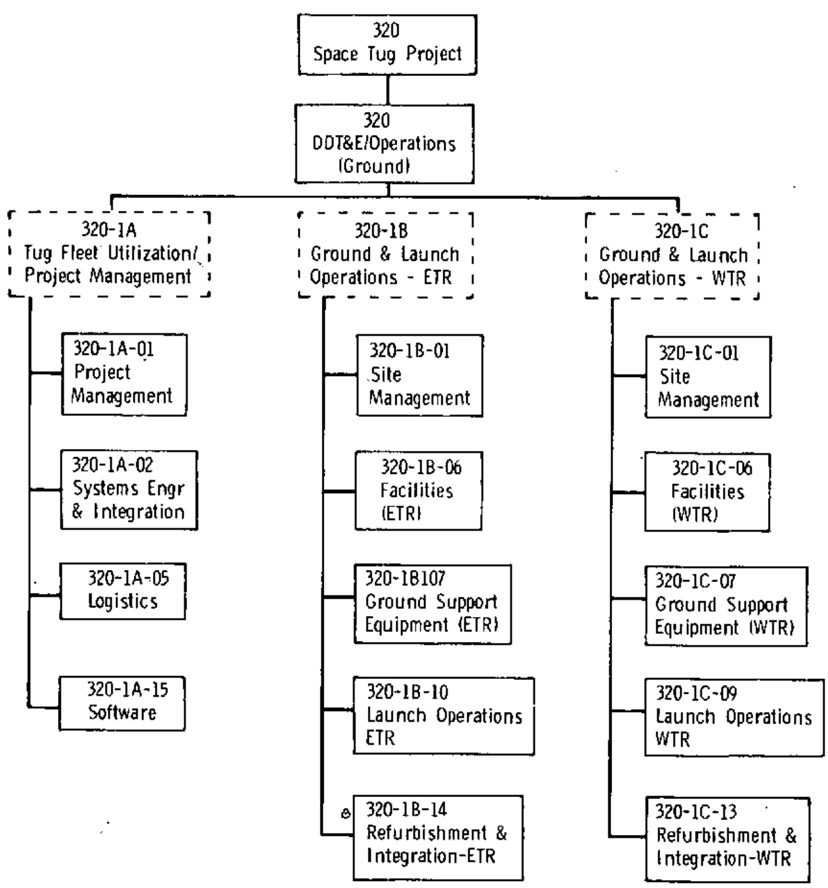

Figure III-34 Tug WBS

The costs summarized in Table III-9 are total costs of the related WBS items for the DDT&E. These costs are incurred from January 1980 to January 1984, which is the start date for operations. Elements common to the operations phase, such as launch operations and refurbishment and integration, were not included in the DDT&E phase. The additional costs of the processing of the test article and first vehicle checkout before launch were distributed into the DDT&E phase WBS elements, because the study ground rule included the first flight article in DDT&E costs.

Table III-9 DDT&E Phase Costs 1980-1984 (Millions of Dollars)

Tug Fleet Utilization Project		$ 7.61
Project Management	$2.43	
Systems Engineering and Integration	2.49	
Logistics	1.01	
Software	1.68	
Ground and Launch Operations, ETR		23.93
Site Management	1.28	
Facilities	11.89	
GSE	10.76	
Ground and Launch Operations, WTR		5.00
Site Management	.08	
Facilities	2.99	
GSE	1.93	
Total Cost		$36.54

The costs relating to the operations phase, defined as the launch of the first vehicle, are total program costs from January 1984 thru December 1991. Those costs are shown on Table III-10. The listed WBS element contains the total cost of each of the WBS elements.

The average cost/flight is derived from the total operations phase costs and the total number of flights. Comparisons on other basis such as cost/flight/year will vary the average because of the launch rate is not constant but the manpower is constant.

Table III-10 Operations Phase Costs 1984-1991
(Millions of Dollars)

		Project Function
Tug Fleet Utilization Project		\$ 58.26
Project Management	\$11.54	
System Engineering and Integration	11.89	
Logistics	21.78	
Software	13.05	
Ground and Launch Operations, ETR		48.24
Site Management	1.83	
Facilities	9.13	
GSE	2.14	
Launch Operations	12.95	
Refurbishment and Integration	22.19	
Ground and Launch Operations, WTR		5.55
Site Management	.91	
Facilities	1.25	
GSE	.46	
Launch Operations	1.88	
Refurbishment and Integration	1.05	
Total		\$112.05
Average Cost/Flight		\$ 0.68

Although the total flights decreased from about 254 last year to 165 this year the cost per flight for ground operations increased only slightly. This is because of some significant cost savings that are realized as a result of improved concepts. For example:

1) Factory clean environment processing costs less than the 100K clean processing because of elimination of special airlocks on buildings and continuous maintenance costs of the facility filtering system and additional maintenance personnel. Additional maintenance costs alone could run \$100,000 per year.

2) Crew sharing between ETR and WTR to support launches instead of a full-time crew reduced costs at WTR by almost \$5M over the eight years of operations.

3) Central Tug Processing Facility at ETR reduces the duplication of facilities and GSE requirements. Total duplication of the facility would add nearly \$16M to the DDT&E phase costs at WTR.

4) The fleet management approach results in cost savings by providing continuous monitoring of Tug usage requirement and projected usage, thus providing advanced planning on spares procurement, major modifications to the Tug, and advanced assignment of Tugs to spacecraft with the capability of real-time assignment changes due to vehicle capability analyses.

IV Concluding Remarks

IV. CONCLUDING REMARKS

The Space Tug enhances the value of the STS by capturing those payloads requiring high energy orbits and the planetary missions beyond the capability of the Shuttle Orbiter. The Tug will also be used for spacecraft servicing, inspection, and retrieval to obtain the maximum cost benefits from the STS. To realize these benefits and attract potential users, it is imperative that the Tug costs per flight be minimized without sacrificing safety, reliability, and performance.

Several past and current studies address innovations in design concepts. Although cost effective design concepts are necessary and provide one area for reducing costs, perhaps an even more fertile area lies in devising operational concepts that lend themselves to lower cost methods of doing business. Of course, these new methods can be implemented only if they are identified early and the capabilities are built into hardware, system designs, and management concepts.

This study has served that purpose by developing operations concepts and assessing the impact of those concepts on the baseline Tug design and the Orbiter interfaces. Where the baseline design does not support the most efficient method of operation, design changes have been recommended. Where the Tug-to-Orbiter interfaces do not adequately support the Tug operational requirements, the study provides recommendations for improvement. Perhaps one of the most significant contributions of this study, however, is establishment of an "operational attitude" early in the Tug program. Appropriately this operational attitude is expected to solidify early Tug project planning with benefits already derived from the common contractor progress reviews and data exchanges. To be truly effective, the Tug project must continue to develop a maintainable and operationalized design while simultaneously developing appropriate fleet management and operations concepts.

All studies identify new factors that require additional or more in-depth treatment. These candidates for further study arise naturally from intelligence developed in the study or from realization that study results are sensitive to parameters not previously considered. Several candidates have been identified in the final report. Three are of significant concern to merit mention here.

1) Tug Requirement Inputs to WTR Facilities - The WTR Tug facility requirements must be identified early to allow incorporation into the initial conversion criteria. Unlike ETR, WTR does not have the flexibility of two launch complexes for Shuttle. Modification to accommodate the Tug requirements

after initial activation would be expensive and could create potential interference with ongoing WTR Shuttle flights. Ideally, this effort should be performed concurrently with the DOD study scheduled to start in March 1975.

2) Space Tug Influences on IUS Design and Accommodations - Although the Tug will not be operational until late 1983, spacecraft designed to fly on the IUS starting as early as 1980 will fly later on the Space Tug. Some spacecraft launched by the IUS may be retrieved by the Tug. Tug-to-spacecraft interfaces can be standardized for those spacecraft designed to mate with Tug after 1983; however, unless Tug inputs are provided to the IUS accommodations concepts, extensive and costly adaptations may be required for spacecraft designed in the IUS era but having continued usage into the Tug era. The IUS IOC is 1980. To provide meaningful inputs, Tug data should be developed concurrent with the ongoing series of IUS studies.

3) Station Set Inputs - The ETR launch site station sets have been defined to varying levels of detail. Tug requirements for joint usage areas, such as the OPF, PCR, and pad, have not been defined to a corresponding level of detail. Unless Tug requirements are defined sufficiently at the beginning of the Shuttle era conversion period, postconversion modifications to accommodate Tug-unique requirements will be more expensive and time-consuming. Tug station set requirements for joint usage areas should be developed early in 1975; the requirements for Tug-unique facilities, such as the TPF, could be deferred until some later date.